THE NICKEL BULLETIN

Monthly Abstracts of Recent Literature

JULY

1960 Volume 33 No. 7

THE MOND NICKEL COMPANY LIMITED

THAMES HOUSE MILLBANK LONDON SW1

Telephone: VICtoria 3888

INDEX

General Page

Filler Rods and Wires for Inert-Gas Arc Welding Nickel and Nickel-containing Steels 161

Nickel

Evaporation and Diffusion Measurements on Sintered Nickel Cathodes containing Alkaline-Earth Oxides 161
Reaction Kinetics of Porcelain-Enamel/Metal Systems 162
Continuous Compaction of Nickel and Nickel-Iron-Molybdenum Powders by Cyclic Pressing 162
Control of Leaf and Stem Rust of Wheat by Zineb and Inorganic Nickel Salts 162
Spectrographic Analysis of Electronic Nickel 163
Technique for Revealing Sub-Boundaries in Nickel 163

Electrodeposition and Other Coating Methods

Conference on Quality Chromium Plating 164
Raising the Standards of Nickel/Chromium Plating 164
Development of Duplex-Nickel Plating Processes 164
Corrosion-Resistance of Nickel-Plated Zinc Die Castings 165
Deposition and Corrosion-Resistance of Crack-Free Chromium 165
Evaluation of Chromium Overcoatings for Use with Duplex-Nickel Deposits 166
Nickel-Plating of Aluminium Alloys 167
Electrodeposition and Corrosion-Resistance of Nickel-Aluminium Alloys 167
Evaluation of Porosity and Cracking in Electrodeposits by the Electrographic-Printing Technique 168
Electron-Probe Technique for Determination of the Thickness of Electrodeposited Coatings 168

Non-Ferrous Alloys

Constitution of the Ni-Al-Si, Ni-Mo-Ti and Ni-Cr-Si Systems 168
Filler Wire for Arc Welding Aluminium Bronze 169

Nickel-Iron Alloys

Special-Purpose Alloys for Instrumentation and Electronics 169
High-Resistivity Alloys with Rectangular Hysteresis Loops 170
Solubility of Carbon in Molten Iron-Nickel Alloys 170

Heat- and Corrosion-Resisting Materials Page

Influence of Mode of Stressing in Fatigue Testing 170
Portable Creep-Testing Unit with Autographic Extensometer 171
Tensile and Short-Time Creep Properties of 'N-155' Sheet 171
'CD-4MCu' Precipitation-Hardenable Casting Stainless Steel 171
'Metamic 247': Nickel/Mullite High-Temperature Bearing Material 172
Embrittlement of a 12-4-type Chromium-Nickel-Steel during Heat-Treatment 172
Controlling the Properties of 'Nimonic' Alloys during Manufacture 173
Experience in the Operation of 'Nimonic 80A' Blades in Turbines Burning Natural Gas 173
Relaxation Characteristics of 'Inconel' at Elevated Temperatures 174
Suitability of Nickel-containing Materials for Use in Pressurized-Water Reactors 174
Forging and Arc Welding of 'Inconel' for Nuclear-Power Applications 175
Properties and Applications of Nickel-Molybdenum-base Corrosion-Resisting Alloys 176
Production and Properties of Sintered Stainless-Steel Parts 177
Compositional Effects in the Corrosion of 18-8-Nb and 18-8-Mo Austenitic Steels 178
Corrosion of Stainless Steels by Hot Hydrogen Sulphide 178
High-Temperature Corrosion in Refinery Service 179
Case Histories of Stainless-Steel Failures in Petroleum Refineries 179
Corrosion Problems in a Synthetic Rubber Plant 179
Use of Cupro Nickel in Surface Condensers 180
Corrosion of Nickel-containing Materials in Liquid Fluorine and Liquid Oxygen 180
X-Ray Fluorescence Analysis of Electrolytically-Extracted Residues 180
X-Ray Fluorescence Analysis of Copper-Nickel-Iron Alloys 181
Influence of High-Temperature Exposure on the Corrosion-Resistance of 18-8-type Weld Metals 181

Analysis 182

Patents 182

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Filler Rods and Wires for Inert-Gas Arc Welding of Nickel and Nickel-containing Steels and Alloys

BRIT. STANDARDS INSTN.: 'Specification for Filler Rods and Wires for Inert-Gas Arc Welding. Part 2. Wires for Gas-Shielded Metal-Arc Welding.'

B.S. 2901: *Part* 2: 1960; 30 pp. Price 7/6d.

This British Standard covers 'a series of ferrous and non-ferrous round wires for gas-shielded metal-arc welding, normally supplied on reels'.

The Standard is in two sections. Section I stipulates general requirements with respect to: preferred diameters, tolerances, condition of wire, certificates, reels, weights, reeling conditions, packing and marking. Section II lays down requirements specific to the application and composition of grades of wire designated as follows:

Group A. Steel Wires

A8.Nb. 18/8-Chromium-Nickel Corrosion-Resisting Steel Wire (Niobium Stabilized)
A8.Ti. 18/8-Chromium-Nickel Corrosion-Resisting Steel Wire (Titanium Stabilized)
A10. 25/12 - Chromium - Nickel Heat - Resisting Wire
A10.Nb. 25/12 - Chromium - Nickel Heat - Resisting Steel Wire (Niobium Stabilized)
A10.Ti. 25/12 - Chromium - Nickel Heat - Resisting Steel Wire (Titanium Stabilized)
A11. 25/20 - Chromium - Nickel Heat - Resisting Steel Wire
A11.Nb. 25/20 - Chromium - Nickel Heat - Resisting Steel Wire (Niobium Stabilized)
A11.Ti. 25/20 - Chromium - Nickel Heat - Resisting Steel Wire (Titanium Stabilized)
A12. Molybdenum - Bearing Chromium - Nickel Corrosion-Resisting Steel Wire
A12.Nb. Molybdenum - Bearing Chromium - Nickel Corrosion-Resisting Steel Wire (Niobium Stabilized)
A12.Ti. Molybdenum - Bearing Chromium - Nickel Corrosion-Resisting Steel Wire (Titanium Stabilized)
A15. Low Carbon Steel Wire
A16. Medium Carbon Steel Wire
A17. Low Carbon Steel Wire.

Group C. Copper and Copper Alloy Wires

C7. Copper Wire
C8. Copper Wire
C9. Silicon Bronze Wire (Copper-Silicon)
C10. Phosphor Bronze Wire (Copper-Tin)
C11. Phosphor Bronze Wire (Copper-Tin)
C12. Aluminium Bronze Wire (Copper-Aluminium)
C13. Aluminium Bronze Wire (Copper-Aluminium)
C17. Cupro-Nickel Wire
C18. Cupro-Nickel Wire
C19. Copper-Nickel-Iron Alloy Wire
C20. Aluminium Bronze Wire (Copper-Aluminium-Nickel)

Groups G and NG. Aluminium and Aluminium Alloy Wires

G1. 99·99 Per Cent. Pure Aluminium Wire
G1A. 99·8 Per Cent. Pure Aluminium Wire
G1B. 99·5 Per Cent. Pure Aluminium Wire
G1C. 99 Per Cent. Pure Aluminium Wire
NG21. Aluminium-5 Per Cent. Silicon Alloy Wire
NG5. Aluminium-3½ Per Cent. Magnesium Alloy Wire
NG6. Aluminium-5 Per Cent Magnesium Alloy Wire

Group NA. Nickel and Nickel Alloy Wires

NA32. Nickel Wire
NA33. Nickel-Copper Wire
NA34. Nickel-Chromium Wire

NICKEL

Evaporation and Diffusion Measurements on Sintered Nickel Cathodes Containing Alkaline-Earth Oxides

J. F. RICHARDSON and F. A. VICK: 'Evaporation and Diffusion Rate Measurements on Cathodes of Sintered Nickel Containing Alkaline-Earth Oxides.'

Brit. Jnl. Applied Physics, 1960, vol. 11, Feb., pp. 73–7.

Determination of the evaporation rates of the alkaline-earth metals and their oxides from oxide-coated and dispenser cathodes are important, since loss of alkaline-earth material by evaporation is the main factor influencing the life of the cathode. In the work reported, the evaporation rate of barium from, and the diffusion rate of barium through, a sintered nickel cathode were determined concurrently, using a radioactive tracer, ^{140}Ba.

In their discussion of the test data presented, the authors conclude that barium and barium oxide move towards the cathode surface by two mechanisms: one, which predominates at temperatures below 875°C., is by diffusion along the pore walls: the other, which predominates above 875°C., is by Knudsen flow through the pores, following evaporation from the pore walls. The activation energies of (a) evaporation, (b) surface diffusion, (c) the low-temperature bulk diffusion process, and (d) the higher-temperature diffusion process are, respectively, (a) 2·2–2·5 eV, (b) 0·89 eV, (c) 0·5 eV, and (d) 2·5 eV.

Reaction Kinetics of Porcelain-Enamel/Metal Systems

R. M. SPRIGGS and A. L. FRIEDBERG: 'Reaction Kinetics of Porcelain-Enamel/Metal Systems.'

Jnl. Amer. Ceramic Soc., 1960, vol. 43, May 1, pp. 252–262.

The investigation reported was undertaken to evaluate the reaction kinetics of the elevated-temperature fusion reactions between various powdered metals and powdered sodium-borosilicate porcelain-enamel glasses containing single metallic ions. Nickel, cobalt, iron and magnesium were employed as the powdered metals; the metallic ions were copper, nickel, cobalt and iron. The reactions were studied as a function of time, temperature, and the concentration of metallic ion in the glass, and it was hoped that the results would throw light on such factors as adherence, gas evolution, and the plating or precipitation of metallic crystals at or near an enamel/metal interface, and, in general, contribute to the prediction of the behaviour of all such systems related to metal/metal-ion reactions in porcelain-enamel and glass/metal technology.

The amount of metallic ion in each reaction which had been reduced to the metallic state by the metal addition was determined by quantitive X-ray diffraction. Specific reaction rates were calculated, their temperature dependence was demonstrated using the Arrhenius equation, and activation energies were established from the slope of these curves.

The over-all results are shown to be in accordance with general theory of chemical kinetics: with the exception of those frits containing the iron ion (which, when coupled with cobalt or nickel metal, resulted in probable reduction of the iron ion to a lower valence, but not to the metallic state), the amount of metallic ion reduced increased with increase in time, temperature and metallic-ion content. Inversions in the order of magnitude of reaction rates for two different metals with the same metallic ion frequently occurred at certain times and temperatures.

The results of this study indicate that the interfacial reactions which might take place between a ground-coat enamel and iron would be strongly favoured in the direction

$$Fe + CoO(NiO) \rightarrow FeO + Co(Ni),$$

and very little tendency would exist for the reverse to occur.

Continuous Compaction of Nickel and Nickel-Iron-Molybdenum Powders by Cyclic Pressing

C. DEIBEL, D.R. THORNBURG and F. EMLEY: 'Continuous Compaction by Cyclic Pressing.'

Powder Metallurgy, 1960, No. 5, pp. 32–44.

Until recently, direct rolling was the only important method capable of continuously compacting powders, and the data available indicate that the maximum thickness attainable in green sheet or strip produced by this method is in the region of ¼ in. (0·6 cm.). The continuous-compacting technique developed by the authors is capable of producing wide bars, of unlimited length, to a uniform thickness, the upper limits of which are analogous to these associated with closed-die compaction. Experimental bars produced to date have been up to 2 in. (5 cm.) in width, but wider sections will, it is anticipated, be easily produced. This paper describes the process and discusses potential applications.

In operating the process, powder is placed in a channel-shaped container, which may be as long as desired. The powder is compressed with a punch consisting of a flat pressing surface (the 'finishing area') which is parallel to the powder surface, and a second pressing surface, faired to the first, which is at an angle to the powder surface. The pressure exerted by the punch thus decreases from the maximum available under the finishing area, to zero at the end of the angled surface. After the pressure stroke, the punch is raised and the powder is moved as a unit until most of the compacted powder is past the finishing area and the following region (which has already received some preliminary compaction from the angled surface) is under the finishing area and ready for final compaction by the next pressure stroke. The sequence is then repeated until the required length of powder has been compacted.

In the many types of material pressed by the technique, the compaction achieved was similar to that produced by conventional pressing. In the present paper the process, and the results obtained by its use, are illustrated by a description of its application to the pressing of various nickel powders prior to sintering and rolling, and to the production of a nickel-iron-molybdenum magnetic alloy from powders of its constituent metals.

The data presented demonstrate the high quality of strip produced from carbonyl-nickel powders, and exemplify the satisfactory magnetic properties of a 79-17-4 nickel-iron-molybdenum high-permeability alloy produced in the form of strip.

Control of Leaf and Stem Rust of Wheat by Zineb and Inorganic Nickel Salts

F. R. FORSYTH and B. PETURSON: 'Control of Leaf and Stem Rust of Wheat by Zineb and Inorganic Nickel Salts.'

Plant Disease Reporter, 1960, vol. 44, Mar. 15, pp. 208–11.

The results of investigations carried out at Winnipeg in 1957 and 1958 had indicated that the inorganic salts of nickel, particularly the chloride and nitrate, could be used to control leaf rust on Thatcher wheat in the field (see papers referred to in *Nickel Bulletin*, 1959, vol. 32, No. 8, pp. 248–9). The increased yields resulting from the application of inorganic nickel were not, however, as great as those arising from the use of the protective fungicide zineb. Consequently, small field plot tests were conducted in 1959 in an attempt to confirm the findings of 1957 and 1958, to extend the investigation to other varieties of wheat, and to ascertain whether or not the same effects could be anticipated in the presence of both leaf and stem rust. The

results of these field tests are reported in the present paper.

The efficacy of the following fungicides was assessed in terms of their capacity to control leaf and stem rust in Thatcher, Marquis and Red Bobs wheat: zineb; nickel chloride+zineb; nickel sulphate+zineb; nickel nitrate; nickel chloride; and nickel sulphate.

Economic control was attained with all the combinations of nickel and zineb studied, the greatest net gain resulting from the use of zineb as a protectant (at the rate of 2½ lb. per acre, with six applications). Benefits resulting from the use of zineb+nickel salts on an eradicative schedule were, due to the fact that the zineb component of the mixture is considerably more expensive than the nickel, not in direct proportion to the increased yields. The data indicate that nickel sulphate, applied at rates of 1-1½ lb. per acre, with intervals of seven days between applications, is an efficient eradicative fungicide of leaf and stem rust on the three types of wheat investigated.

Spectrographic Analysis of Electronic Nickel

G. P. MITCHELL and G. ORME: 'The Analysis of Nickel. Part II. The Application of a Spectrographic Solution Technique to the Analysis of Nickel.'

Metallurgia, 1960, vol. 61, Apr., pp. 185-90.

In Part I of the paper* a description was given of the chemical procedures devised for the determination of the elements present as alloying additions or impurities in 'electronic grades' of nickel. Whilst these procedures are suitable for rapid routine determinations, the logical course, if routine analysis is contemplated on a regular scale, is to employ a spectrograph. Part II of the paper is therefore concerned with two spectrographic methods suitable for analysis of electronic nickel. The analytical requirements which must be satisfied by such spectrographic analysis are reproduced below:

Element	*Range (%)*
Magnesium	0·001–0·20
Cobalt	0·001–1·0
Copper	0·005–0·30
Manganese	0·001–0·50
Iron	0·005–0·50
Titanium	0·005–0·10
Aluminium	0·005–0·20
Chromium	0·001–0·20
Silicon	0·001–0·50

* T. R. ANDREW and C. H. R. GENTRY, *Metallurgia*, 1959, vol. 60, pp. 27-30, 69-72, 121-4, 173-6; see abstract in *Nickel Bulletin*, 1960, vol. 33, No. 1-2, p. 4.

The first method, a powder technique suggested by E. K. Jaycox, and subsequently put forward as a tentative method of nickel analysis by the American Society for Testing Materials, is discussed only from the point of view of the modifications which the authors consider necessary for routine practice. A disadvantage of the Jaycox method is the relatively long period of time required for the preparation of samples prior to spectrographing, a disadvantage which becomes more serious as the number of samples submitted for analysis increases. A more rapid preparation technique was necessary, and, with this aim in mind, a study was made of the feasibility of developing a direct-solution method of analysis of electronic nickel. The technique which resulted from this study forms the main subject of this paper. (The Jaycox procedure must, however, it is stated, still be used for sample weights less than approximately 100 mg.)

The direct-solution technique described is based on the use of a new solution electrode of cup type. Details of the electrode are given, and its performance, as determined in exploratory experiments, is discussed. Finally, the procedure evolved for analysis of electronic nickel is outlined, and typical results are reported. The advantages of the technique are fully considered.

Technique for Revealing Sub-Boundaries in Nickel

D. HARDWICK, H. ORMEROD, and W. J. McG. TEGART: 'A Technique for Revealing Sub-Boundaries in Nickel.'

Jnl. Inst. Metals, 1960, vol. 88, May, pp. 414-5.

During an investigation of the structural changes produced in metals by torsional deformation at high temperatures and high strain rates, it became necessary to examine the structure of commercially-pure nickel after various deformations and rapid quenching to room temperature. On the basis of previous observations on copper and aluminium deformed under equivalent conditions, it was suspected that both polygonization and recrystallization might be operative in different sections of the specimens, depending on local strain conditions.

Sub-boundaries were developed by etching the specimens electrolytically in a solution (consisting of glacial acetic acid 5, nitric acid 10, water 85, ml.) recommended by Kehl for grain-size determination. A platinum cathode was employed; optimum conditions were 3·6V. for 30 seconds. The best results were obtained on specimens mechanically polished to a fine diamond finish (chemical polishing led to relief effects which were accentuated by the electrolytic etching).

Typical structures in nickel torsion specimens deformed at 950°C. are shown.

Filler Rods and Wires for Inert-Gas Arc Welding Nickel

See abstract on p. 161.

ELECTRODEPOSITION AND OTHER COATING METHODS

Conference on Quality Chromium Plating

'Confidence in Plating: An Account of a Conference at The Engineering Centre, Birmingham, Feb., 1960.'*
Report issued by THE MOND NICKEL COMPANY, LTD., 1960; 67 pp.

This publication contains the proceedings of a conference organized by The Mond Nickel Company, Ltd., as a means of throwing light on the aims and salient features of the Company's 'Quality Label' Scheme, the basis of its campaign to eliminate sub-standard nickel/chromium plating.

The Company's campaign is intended to ensure: (1) that components are plated in accordance with the requirements of *British Standard* 1224: 1959; (2) that the customer becomes 'quality-conscious'; and (3) that public confidence in a nickel/chromium finish is increased. The colour of the labels, which the Company issues to manufacturers at cost price, denotes the suitability of a specific coating for severe (red), moderate (blue) or mild (green) service. Manufacturers are required to undertake that the labels will be employed correctly on plating *tested* to *B.S.* 1224: 1959.

Papers presented at the Conference, and included in the report, are listed below. Designed to cover the most important factors involved in improving the quality of nickel/chromium plating, they gave rise to interesting discussions, which are also reported.

G. E. SANDLAND: 'Labelling Plated Goods to the British Standard', 7 pp.
E. A. OLLARD: 'British Standard 1224: 1959', 5 pp.
H. C. CASTELL: 'The Value of Specifications in Decorative Nickel and Chromium Plating', 7 pp.
S. W. BAIER: 'The B.N.F. Plating Gauge', 7 pp.+figures.
J. D. EDWARDS: 'Corrosion Testing', 10 pp.
G. N. FLINT: 'Corrosion-Resistance of Nickel/Chromium Plating', 7 pp.+figures.
R. J. BROWN: 'The Care of Plated Parts', 9 pp.
D. N. LAYTON: 'The Effect of Design on Plateability', 8 pp.+figures.

Raising the Standards of Nickel-Chromium Plating

'Your Chromium Will Soon Last Longer.'
Engineering, 1960, vol. 189, June 3, pp. 742-3.

This article, written in the light of the doubts which have, since the war, been cast on the adequacy of nickel/chromium plating in the U.K., gives details of the positive action which, now that nickel is in plentiful supply and can be used in greater thickness to increase the corrosion-resistance of the composite coating, is being taken to improve plating quality.

The British Standards Institution has issued a new criterion of plating quality, *B.S.* 1224: 1959, which lays down requirements for three grades of plating, and provides for thicker coatings of nickel (see table and abstract in *Nickel Bulletin*, 1959, vol. 32, No. 12, pp. 350-1). The British Non-Ferrous Metals Research Association has developed a new measuring instrument to determine the thickness of the electrodeposits (see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 12, pp. 351-2). Finally, The Mond Nickel Company, Ltd., as one of the world's major suppliers of nickel, has evolved a Quality Label scheme by which labels will be affixed to plated components as an indication that the plating is in accordance with one of the grades covered by *B.S.* 1224: 1959. The conjoint efforts of these organisations, which, it is hoped, will eliminate faulty plating, are discussed in the first section of the article.

In other sections, brief consideration is given to three factors of immediate relevance to any attempt to improve plating standards: the degree to which the results of accelerated-corrosion tests reflect the service performance of electrodeposited coatings on car components; the validity of claims concerning the improvements in corrosion-resistance conferred by the incorporation of duplex nickel into the composite coatings; and the effects of increasing the thickness of the final chromium overcoating.

An interesting feature of the article is a table outlining the salient characteristics of four duplex-nickel processes available in the United Kingdom.

Development of Duplex-Nickel Plating Processes

M. M. BECKWITH: 'The Development of Duplex-Nickel Plating Process.'
Plating, 1960, vol. 47, Apr., pp. 402-4.

In this paper the author outlines the events which led to the introduction of the duplex-nickel plating process developed by the Harshaw Chemical Company, and discusses the factors which contribute to the superior corrosion-resistance of the coating produced by the process.

The semi-bright constituent of the duplex coating is deposited by a process (the 'Perflow') originally evolved, in 1945, as a replacement for a Watts-type solution. At that time, the duplex coating was employed as a means of eliminating or minimizing the buffing operations which previously had been necessary after nickel plating and before chromium plating, but subsequently, with the realization that the duplex system could confer greater corrosion-resistance on zinc die castings, a bright-nickel solution (the 'Perglow') was evolved specifically to provide a bright deposit compatible with the semi-bright nickel. This duplex plating process was introduced on a commercial scale in 1957.

In discussing the corrosion-resistance of duplex nickel the author makes the following points:

It has been observed that pitting penetration, which, in the case of bright nickel, progresses continuously to the basis metal, slows down markedly at the duplex-nickel interface. Pitting then proceeds slowly laterally, with a greatly reduced rate of vertical penetration. This effect is attributed not to the radically different structures of the two nickel layers, but to the superior

* *We shall be pleased to supply a free copy of this report of the proceedings of the Conference.*

corrosion-resistance of the sulphur-free semi-bright nickel.

Both duplex-nickel and bright-nickel coatings are subject to surface pitting as a result of accelerated testing or atmospheric exposure. The duplex-nickel system is, however, undoubtedly superior from the point of view of protecting the basis metal from corrosion.

The improvement yielded by a duplex-nickel system varies greatly with the type of bright nickel used as the overcoating. One cause of this variation may be the potential differences between the various types of bright-nickel deposit and the semi-bright nickel of the duplex system.

Corrosion-Resistance of Nickel-Plated Zinc Die Castings

W. H. SAFRANEK, H. R. MILLER, R. W. HARDY and C. L. FAUST: 'Data on the Corrosion-Resistance of Electroplated Zinc Die Castings.'

Plating, 1960, vol. 47, Apr., pp. 405–11.

The investigations reported were conducted, at Battelle Memorial Institute, under the aegis of the American Zinc Institute, in a search for practical methods of improving the corrosion-resistance of nickel/chromium-plated zinc die castings. The three test programmes were initiated consecutively at approximately yearly intervals.

In Programme I, which began in 1957, a study was made of: (1) the effects, on the corrosion-resistance of copper/nickel/chromium coatings, of increasing the thickness of the copper and nickel deposits; (2) crack-free chromium; (3) cobalt and cobalt-nickel-alloy electrodeposits; (4) the effect, on corrosion-resistance, of substituting electropolishing and levelling zinc plating for mechanical buffing.

The study of crack-free chromium was continued under Programme II, the scope of which also covered an investigation of the performance of duplex-nickel coatings and additional studies of the effects of varying the thickness of the copper and nickel constituent deposits. (For the purposes of comparison, stainless steel and anodized aluminium were included in this programme.)

In Programme III the corrosion-resistance of composite coatings was investigated as a function of the thickness of the duplex-nickel and crack-free-chromium constituents. Coatings consisting of chromium/nickel/chromium, bright-nickel/duplex-chromium, and duplex-nickel/duplex-chromium were also evaluated in this third phase.

Corrosion-resistance was assessed in terms of the effects of atmospheric exposure and of the results of the 'Corrodkote', copper-accelerated salt-spray, and acetic-acid/salt-spray corrosion tests.

Programme I gave rise to the following findings:

(1) Chromium deposited, in a bright, crack-free form, to a thickness of 0·08 mil. remained free from cracks and provided excellent corrosion protection for the entire 90-week outdoor-exposure period.

(2) Increasing the thickness of the chromium and depositing it in a crack-free form was more effective in improving corrosion-resistance than increasing the thickness of the copper by 75 per cent. and increasing that of the nickel by 62 per cent.

(3) A composite coating consisting of copper/nickel/chromium/nickel/chromium was very effective in preventing basis-metal corrosion. With a final chromium thickness of only 0·01 mil, however, surface pitting was pronounced.

(4) Corrosion was reduced somewhat by substituting electropolishing and levelling zinc plating for mechanical buffing.

Programme II confirmed the efficacy of crack-free chromium and demonstrated the satisfactory corrosion-resistance of a duplex-nickel coating incorporating a semi-bright nickel deposit with a columnar structure. Inferior results were obtained with a duplex-nickel composite, the semi-bright layer of which exhibited a banded structure. A composite of duplex nickel + 0·02 mil of chromium was more satisfactory than one consisting of a similar duplex-nickel layer + only 0·01 mil of chromium.

The need for a chromium overcoating thicker than 0·01 mil was confirmed in Programme III, which involved tests on duplex-nickel coatings 0·4, 0·8 and 1·2 mil thick. The performance of a composite comprising 0·055 mil of crack-free chromium over 0·4 or 0·8 mil of duplex nickel was much better than that of one consisting of only 0·01 mil of chromium over the same thickness of duplex nickel. Unsightly corrosion pits were observed when 0·01 mil of chromium was used as an overcoating for 1·2 mil of duplex nickel, whereas 0·055 mil of crack-free chromium prevented such pitting. Composites of 0·8 or 1·2 mil of duplex nickel + 0·055 mil of crack-free chromium conferred protection superior to that of the other composites included in the programme.

The overall conclusion drawn from the comprehensive data presented in the paper is that optimum protection is obtained when the nickel constituent of a duplex-nickel/crack-free-chromium composite is at least 0·8 mil thick and the crack-free chromium at least 0·025 mil thick (and preferably about 0·055 mil in the low-current-density areas).

Deposition and Corrosion-Resistance of Crack-Free Chromium

W. H. SAFRANEK, H. R. MILLER and C. L. FAUST: 'The Corrosion Protective Characteristics of Decorative Chromium Plate.'

Plating, 1960, vol. 47, May, pp. 513–9.

Soon after the revival, in 1958, of interest in high-temperature, high-ratio chromium-plating solutions, a comprehensive test programme was undertaken at Battelle Memorial Institute to establish conditions for deposition of improved chromium coatings. The results of this investigation form the subject of the present paper.

During the investigation several hundred zinc die-cast panels were polished, buffed and plated with 0·4 mil of copper and 0·8 mil of bright nickel. The copper- and nickel-plating procedures were carefully controlled to ensure uniformity in quality and thickness. The panels were then plated with chromium

(0·004–0·35 mil thick) from solutions (1) varying in chromic-acid, sulphuric-acid and trivalent-chromium concentration and in the chromic-acid/sulphuric-acid ratio, and (2) operated at different temperatures and current densities. The effects of these variations, as reflected in the quality of the coatings, were assessed in terms of the results of exposing the plated panels to the 'Corrodkote' and electrographic-printing tests. On the basis of this assessment, the following solution composition and plating conditions were established as optimum for deposition of pore-free, crack-free chromium:

Chromic-acid concentration	45–47 oz./gal. 281–293 g./L.
Sulphuric-acid concentration	0·29–0·30 oz./gal. 1·8–1·86 g./L.
Chromic-acid/sulphuric-acid ratio	150:1–160:1
Trivalent-chromium concentration	0·5 g./L. min.
Temperature	130°±2°F. 54°±1·1°C.
Cathode current density	
Best for bright deposits	300–350 amp./sq. ft. 32·4–37·8 amp./dm.²
Permissible range for crack-free and pore-free deposits	150–350 amp./sq. ft. 16·2–37·8 amp./dm.²

Porosity is markedly reduced when the thickness of the chromium deposit is increased to 0·025 mil: chromium deposited, on smooth surfaces, at a thickness of 0·05 mil or higher is essentially pore-free.

Evaluation of Chromium Overcoatings for Use with Duplex-Nickel Deposits

M. R. CALDWELL and L.B. SPERRY: 'Evaluation of Modern Methods of Improving the Corrosion-Resistance of Plated Zinc-base Die Castings.'

Plating, 1960, vol. 47, Apr., pp. 396–401.

As a result of a comprehensive series of corrosion tests extending over a period of more than four years, the Doehler-Jarvis Division, National Lead Company, convinced that the duplex-nickel plating process developed by them (under the name of 'Doehler Double Plate') offered the most logical and economical method of enhancing the protection conferred on zinc-base die castings, incorporated the process as the nickel-deposition stage in the plating of car components. Subsequently a supplementary programme of corrosion tests was initiated to determine the type of chromium overcoating which would give optimum results when used in conjunction with a duplex-nickel coating. The initial results of this programme are reported in the present paper.

The chromium coatings evaluated were deposited, to thicknesses in the range 0·01–0·05 mil, on panels previously plated with 0·0008 in. (0·02 mm.) of duplex nickel over 0·0004 in. (0·01 mm.) of copper. The types of chromium-plating solution employed are indicated in the table below. The two sulphate solutions were used both individually and in conjunction (to produce one duplex coating); duplex deposits were also produced using the two fluoride-type solutions. Four sets of panel were plated, each consisting of nine groups of four panels (two of the four panels in each group being baked). The panels were subjected to (1) electrographic-printing tests; (2) the 'Corrodkote' test (five 20-hour cycles); (3) the CASS tests (five 16-hour cycles); (4) atmospheric exposure on a roof in Detroit (data from these tests will not be available for some considerable time). The results of the first three tests are discussed in relation to electrographic prints of chromium deposits of different thickness and type, or to numerous photomicrographs indicating the effects of the 'Corrodkote' and CASS tests.

The chromium coatings which, in the authors' opinion, gave the best overall performance in the accelerated-corrosion tests were:

Sulphate type—0·01 mil thick;
Duplex sulphate type—0·03 mil thick;
Fl type A—0·05 mil thick.

No significant basis-metal corrosion was observed with any of these coatings. Only surface pitting was noted in the case of the 0·01-mil sulphate-type (baked or unbaked) chromium overcoating, and in the 'Corrodkote' test no pitting had occurred either on the baked or unbaked panels until after two 20-hour cycles. The 0·03-mil duplex sulphate-type chromium deposit was found to be subject, in the as-deposited condition, only to surface pitting; after baking treatment only cracking was observed. The 0·05-mil Fl-type chromium deposit showed evidence only of cracking, which, however, was increased by a baking treatment.

Until the achievement of the ultimate aim of a reasonably thick crack-free chromium deposit, deposition of 0·01 mil. of sulphate-type chromium will, it is considered, result in as good an overcoating for duplex nickel as any of those tested.

Chromium Plating Solutions Studied

(*See abstract above*)

Designation	Anion	Ratio	Temperature		Current Density		CrO_3	
			°F.	°C.	amp./sq. ft.	amp./dm.²	oz./gal.	g./L.
SO_4 Type	SO_4	100–1	110	45	195	21	32	200
Hi CRT*	SO_4	150–1	130	55	230	24·8	45	281
Fl Type A	Fl_xSO_4	—	120	50	260	28	49	306
Fl Type B	Fl_xSO_4	—	120	50	195	21	26	162

* This high-concentration, high-ratio, high-temperature bath was selected for study because of its outstanding merit with respect to cracking.

Nickel Plating of Aluminium Alloys

J. T. N. ATKINSON: 'Novel Process for Plating Nickel on Aluminium Alloys.'

Plating, 1960, vol. 47, May, pp. 509–12.

Earlier work had indicated the feasibility of electrodepositing nickel directly on to aluminium from an acid plating solution, which, whilst otherwise of conventional characteristics, would, under its normal operating conditions, approach the threshhold of corrosiveness to aluminium alloys and permit deposition of a good quality coating without the need for zincate or other complex pre-treatments. (The oxide film present on the aluminium basis metal is thinned in a mild-alkaline cleaning stage, and its remnants are then removed cathodically in the initial stages of plating from the acid electrolyte.) The most promising solution previously studied contained nickel sulphate, nickel fluosilicate and boric acid, and was operated at a pH in the region of 2·7. In view of the marked similarity between fluoborates and fluosilicates, and the much better plating characteristics of the latter, attempts were made to develop an analogous fluoborate solution. These attempts are described in the present paper.

It soon became apparent that closely controlled additions of chlorides could render the fluoborate solutions very effective. Considerable work was therefore carried out to determine the proper operating range of the bath: the composition and operating conditions of the solution finally developed are noted below.

Composition and Operating Conditions	Preferred Value	Permissible Range
Nickel-sulphate crystals	200 g.	100-400 g.
Nickel-fluoborate crystals	66 g.	132-33 g.
Nickel-chloride crystals	1 g.	½-1 g.
Boric acid	20 g.	10-40 g.
Water to make ..	1 litre	1 litre
pH	1·0	0·9-1·5
Operating temperature	60°C.	50-70°C.

Solution control, the procedure employed in nickel plating aluminium and the adhesion of the nickel deposit are discussed.

The process is considered applicable also to the direct plating of a range of other materials, including mild steel and stainless steel.

In an *Appendix* to the paper (pp. 511–12) D. G. GAGE, A. SCHLOSSBERG and M. HEIT give details of the analytical methods developed for routine control.

Electrodeposition and Corrosion-Resistance of Nickel-Aluminium Alloys

D. E. COUCH and J. H. CONNOR: 'Nickel-Aluminium Alloy Coatings Produced by Electrodeposition and Diffusion.'

Jnl. Electrochemical Soc., 1960, vol. 107, Apr., pp. 272–6.

Nickel-aluminium alloys are hard, resistant to corrosion at normal temperatures, and very resistant to oxidation in air at temperatures in the range 500–1100°C. Although alloys of this type have been prepared by metallurgical methods, their brittleness renders the manufacture of intricately-shaped objects difficult. As protective coatings, however, they would offer valuable advantages, and the investigation now described was undertaken (1) to determine some means of electrodepositing such alloys, and (2) to evaluate the oxidation- and corrosion-resistance of the coatings produced.

Attempts to co-deposit nickel and aluminium from organic-type baths proved unsuccessful. Other experiments, using fused-salt baths, indicated the feasibility of co-depositing the two metals from a bath containing sodium chloride, potassium chloride, cryolite, and nickel chloride (at current densities of 100 amp./dm.^{2} or greater). The deposits contained 30–50 per cent. of aluminium, but unfortunately were very thin: efforts to produce deposits 25μ thick resulted in the formation of thin coherent layers covered with a black non-coherent material. This approach was therefore abandoned in favour of study of fused-salt baths used for electrodeposition of aluminium. The intention was to electrodeposit a coating of aluminium over nickel and, by diffusion (either during or after the plating operation), to produce a nickel-aluminium-alloy layer.

Of the fused-salt baths studied, the following were found to be the most satisfactory:

(1) Sodium chloride	440 g.
Potassium chloride ..	560 g.
Cryolite	150 g.
Temperature	700°–800°C.
Current density	2–10 amp./dm.^{2}
Anodes	graphite.
Container..	graphite.

Alloy deposits 25–75μ thick contained 43–52 per cent. of aluminium.

(2) Aluminium chloride (anhydrous)	900 g.
Sodium chloride	200 g.
Temperature	160°–180°C.
Current density	1–4 amp./dm.^{2}
Anodes	tungsten or graphite.
Covered container ..	glass ('Pyrex' or equivalent).

Little diffusion occurred during plating and it was necessary to subject the specimens to a post-plating diffusion treatment to ensure formation of the alloy: data presented indicate the times required for diffusion of various thicknesses of aluminium into nickel.

Steel panels coated with nickel-aluminium alloy were subjected to metallographic examination and to oxidation, salt-spray and atmospheric-exposure tests. The data derived from this evaluation show that the oxidation- and corrosion-resistance of the nickel-aluminium coatings are superior to those of nickel electrodeposits. Depending on the thickness of the coating and the type of bath used, the Knoop hardness of the alloy coatings varied in the range 611–788.

Evaluation of Porosity and Cracking in Electrodeposits by the Electrographic-Printing Technique

H. R. MILLER and E. B. FRIEDL: 'Developments in Electrographic Printing.'

Plating, 1960, vol. 47, May, pp. 520–7.

The electrographic-printing technique was first employed by Glazunov to locate flaws in metals. Subsequently the scope of the process was extended to the field of electroplating, and the technique, as modified by Battelle Memorial Institute, has, for example, permitted rapid assessment of porosity and cracking in chromium deposits produced under varying plating conditions (see abstract of paper by SAFRANEK *et al.*, p. 165). Details of the improved technique and its application to the evaluation of protective coatings are contained in the present paper.

In carrying out the electrographic-printing process a piece of dye-transfer photographic paper, soaked in a dilute electrolyte solution, is pressed firmly against the surface to be examined. A potential of 1·5 to 6·5 volts direct current is applied, for a time ranging from several seconds to a few minutes, across a 'sandwich' formed by the test part, a suitable metal cathode and by blotter papers (soaked in dilute electrolyte) which separate the two. The specimen is made anodic, and, under the influence of the applied potential, cations from the underlying metal are formed at pores or cracks in the protective coating. The cations enter the gelatinized surface of the dye-transfer paper, and react with appropriate chemicals to form coloured precipitates or soluble complexes. Cracks are shown on the print as coloured lines, while pores appear as coloured dots. The crack patterns or pore sites are reproduced as mirror images. In the Battelle process, the chemical indicators are added directly to the electrolyte in which the dye-transfer paper is soaked, a procedure representing an improvement over previous methods which required at least two steps (transfer of the basis-metal ions to the dye-transfer paper, and development of the transferred ions into coloured chemicals).

The advantages of the process are fully considered.

Electron-Probe Technique for Determination of the Thickness of Electrodeposited Coatings

R. KRIEGLER and B.W. SCHUMACHER: 'Thickness Measurements on Platings by Means of an Electron Probe.'

Plating, 1960, vol. 47, Apr., pp. 393–5.

The electron-probe technique described, evolved at the Ontario Research Foundation as a means of determining the thickness of electrodeposited coatings, takes practical advantage of the energy-range relation of electrons. An electron beam of variable energy is directed into the sample, and the energy at which the electrons penetrate the electrodeposit and reach the basis metal is determined by measuring the acceleration voltage of the electron beam at the appearance of the characteristic X-ray lines from the basis metal.

The experimental procedure is exemplified in this paper by a description of that employed to determine the thickness of nickel coatings deposited on iron specimens and of chromium coatings deposited on nickel. The measured values show close agreement with the thickness values (0·05–0·4 mil in the case of the nickel, 0·05–0·2 mil in the case of the chromium) calculated on the basis of plating time and current used. The experiments were conducted using an atmospheric electron probe and an X-ray spectrometer built mainly for spectrochemical analysis: with current and high-voltage stabilization the accuracy of the technique will, it is anticipated, surpass that of most of the non-destructive methods at present available.

The application of the electron probe is not restricted to any particular basis-metal/deposit combination. It is speedier than the X-ray-fluorescence method, enables determination of thickness at a microspot, and can be used for measurement of coatings ranging from the thinnest to those of centimeter thickness.

NON-FERROUS ALLOYS

Constitution of the Ni-Al-Si, Ni-Mo-Ti and Ni-Cr-Si Systems

R. W. GUARD and E. A. SMITH: 'Constitution of Nickel-base Ternary Alloys. III. Nickel-Aluminium-Silicon System. IV. Nickel-Molybdenum-Titanium System. V. Nickel-Chromium-Silicon System.'

Jnl. Inst. Metals, 1960, vol. 88, Apr., pp. 369–74.

The data reported in the three sections of this paper were derived as part of a series of investigations of nickel-rich ternary systems relevant to work on the development of nickel-base high-temperature alloys (for abstracts of Parts I and II, see *Nickel Bulletin*, 1960, vol. 33, No. 4, pp. 78–9).

Part III of the paper presents the results of a study of the nickel-rich portion of the nickel-aluminium-silicon system. The terminal solid solubility in nickel, and the phase relationships, were determined at 1100°C. Two ternary compounds, ψ and Ξ, were found to exist over very limited ranges of composition: their crystal structures were not determined. It was observed that Ni_3Al and Ni_3Si, although isostructural, do not form a continuous series of solid solutions.

Molybdenum and titanium tend to improve the high-temperature properties of nickel in an appropriately protective atmosphere, and the authors deemed it logical, therefore, to determine, at 900° and 1175°C., the terminal solid solubility in nickel and the phase relationships existing in the nickel-rich section of the nickel-molybdenum-titanium system. The results of the investigation are noted in *Part IV*. Two ternary compounds were present in this portion of the system: one, designated ψ, occurred at approximately nickel 50, molybdenum 27·5, titanium 22·5, at. per cent.; the other, designated Ξ, occurred at the stoichiometric composition Ni_6MoTi. Both compounds undergo some kind of transformation on cooling to room temperature. Their structures are complex and have not been established.

Part V contains the data obtained in a study of the nickel-rich alloys in the nickel-chromium-silicon

system. (Chromium and silicon were selected as alloying additions because of their beneficial effects on the oxidation-resistance of nickel alloys at high temperatures; the authors wished also to compare the system with the nickel-chromium-aluminium system.) Phase relationships and terminal solid solubility in nickel were established at 900° and 1100°C. As in the previous systems examined, at least one ternary compound (designated ψ and lying close to the stoichiometric composition Ni_3Cr_2Si) was found to be present. Its crystal structure was complex and was not determined. The influence of chromium on the solubility of silicon in nickel, and that of silicon on the solubility of chromium, was negligible.

Filler Rods and Wires for Inert-Gas Arc Welding Nickel-containing Alloys

See abstract on p. 161.

Filler Wire for Arc Welding Aluminium Bronze

M. BIRKHEAD and C. V. WILSON: 'Aluminium-Bronze Welded Fabrications. I. II.'

Welding and Metal Fabrication, 1960, vol. 28, Apr., pp. 162–8; May, pp. 198–205.

The suitability of the aluminium bronzes for use in applications involving exposure to high stresses and corrosive environments has increased the demand for a wider range of wrought products and welded fabrications, and resulted in the production of hot-rolled sheet and plate in the single-phase alloys. The α aluminium bronzes are highly ductile and readily formed, and these properties, together with their excellent corrosion-resistance, render them suitable for the manufacture of welded structures. The problems involved in welding such alloys are great, and early attempts to weld α-alloy plate with α filler wire showed that the single-phase alloys are prone to weld cracking in restricted multi-pass welds. In the authors' opinion, the intrinsic hot shortness of the single-phase alloys is responsible for the propensity to hot cracking, and a filler wire of a composition which solidifies first as β, and retains a proportion of β at lower temperatures, would offer the most likely remedy: they support their opinion by a full discussion of the metallurgical factors involved and by reference to relevant equilibrium diagrams and photomicrographs. Consideration of the filler wires which might satisfy these requirements (the suitability of a duplex 90–10 copper-aluminium alloy, a single-phase 7½ aluminium–2½ iron–copper alloy, and a 9½ aluminium–5 nickel–4 iron–copper alloy is assessed) led the authors to the conclusion that the nickel-containing alloy offered the greatest promise as a filler metal. The alloy (which conforms to the requirements of A.S.T.M. B.171 Alloy E) commences solidification as β and possesses high hot ductility. Below the solidus, the β transforms to $\alpha+\varkappa$, affording maximum resistance to corrosion. No brittle γ_2 is formed, since the aluminium content lies below the minimum of the β-γ_2 transformation. Non-equilibrium conditions lead to retention of some β, which is transformed to $\alpha+\varkappa$ by subsequent weld layers, or by post-weld heat-treatment. Early runs are, therefore, softened by later runs, not embrittled. The comprehensive investigation described in the present paper was initiated in an attempt to gain experimental confirmation of the suitability of Alloy E as a filler metal, and, if the attempt were successful, to evolve a welding procedure suitable for application on a commercial scale.

Part I of the paper summarizes the results of tests carried out on simple butt and fillet welds in $\frac{3}{16}$–$\frac{3}{4}$ in. thick aluminium-bronze plate of the following composition (A.S.T.M. B.171 Alloy D), using the inert-gas-shielded tungsten-arc, metal-arc, and inert-gas-shielded metal-arc welding processes: aluminium 7·61, iron 2·68, nickel 0·11, manganese 0·06, per cent., remainder copper.

The results corroborate the metallurgical deductions with respect to hot ductility and the feasibility of producing multi-pass welds free from cracks. Data illustrating mechanical properties of weldments and weld metal are tabulated, and photomicrographs typical of the weld metal in various conditions are included in the paper. In other experiments the influence of post-weld heat-treatment on the structure, hardness and mechanical properties of the weld metal was determined: the results are fully discussed.

Part II of the paper covers a subsequent stage of the investigation, that concerned with (1) an evaluation of the problems associated with the production of welded joints between mild steel and aluminium bronze, and (2), more specifically, the development of welding procedures suitable for layering the faces of mild-steel flanges with aluminium bronze, and welding mild-steel flanges to aluminium-bronze branches and the main barrel. In preliminary tests, the conditions necessary for deposition of sound weld metal with satisfactory fusion zones between the two materials were determined, using Alloy E filler metal deposited by the inert-gas-shielded metal-arc process. Details of the tests are given, and the practical application of the principles and techniques outlined in this preliminary phase is then exemplified by a description of the procedure used in the assembly and welding of return-end and water boxes for a large heat exchanger.

NICKEL-IRON ALLOYS

Special-Purpose Alloys for Instrumentation and Electronics

C. GORDON SMITH: 'Special-Purpose Alloys for Instrumentation and Electronics.'

Engineering Materials and Design, 1960, vol. 3, May, pp. 280–4.

In this article the author reviews the properties and applications of alloys in which the beneficial effects of the nickel constituent are perhaps less familiar and

obvious than those associated, for example, with the nickel content of heat- or corrosion-resisting alloys and steels, i.e., the nickel-iron or nickel-iron-base alloys. The special properties of these alloys, related (either directly, or as an indirect result of volume changes associated with magnetic transformations, to ferro-magnetic phenomena) have been used to great advantage in the fields of instrumentation and electronics, and, bearing in mind that such applications involve, in many cases, components weighing only a few ounces or less, their extent can be judged by the fact that they account for over 5 per cent. of the total amount of nickel produced.

The properties, advantages and applications of the various grades of nickel-iron alloy falling within the scope of the review are discussed under the following heads: square-hysteresis-loop alloys; magnetic-compensation alloys; permanent magnets; magnetostrictive materials; low-expansion alloys; constant-modulus alloys. Brief reference is made to the development of ferrites, and a section on miscellaneous applications covers materials used for springs, thermionic valves, sparking plugs and power-supply applications. The information given in the text is supplemented by curves illustrating the relevant properties of nickel-iron alloys.

High-Resistivity Alloys with Rectangular Hysteresis Loops

A. HART: 'High-Resistivity Nickel-Iron Alloys with Rectangular Hysteresis Loops.'

Brit. Jnl. Applied Physics, 1960, vol. 11, Feb., pp. 58–60.

A 65–35 nickel-iron alloy, which exhibits a rectangular hysteresis loop after magnetic annealing, has been found suitable for use in many applications (e.g., in magnetic amplifiers, mechanical rectifiers, pulse generators, static-delay lines and matrix-type stores): its coercivity *Hc* is about 0·01 Oersted and the remanence ratios *Br*/*Bm*, after saturation in a field of 10 Oersteds, are in the range 0·9–0·95. Its low resistivity (the value of p is only 19×10^{-6} Ω cm.) is often disadvantageous, however, and eddy-current effects limit the performance of many of the devices incorporating the alloy. The investigation described was initiated in an attempt to develop an alloy with similar magnetic characteristics but higher resistivity.

An alloy containing 1 per cent. molybdenum appeared to offer promise in this respect. Test specimens 50μ thick, based on a 65/35 nickel/iron ratio and containing 1½, 2, 3 or 4 wt. per cent. of molybdenum, were therefore prepared by powder metallurgy and subjected to magnetic annealing to determine (1) whether they would offer the desired properties, and (2), if so, the most effective annealing treatment.

The test data tabulated (which are discussed incidentally in relation to the light they throw on the magnetic-annealing process) show that a longer time of anneal, at a temperature lower than normal, successfully produces rectangular loops in alloys with additions of up to 3 wt. per cent. of molybdenum. From the point of view of the *Br*/*Bm* ratio and coercivity, the alloys are practically identical with the straight 65-35 alloy; their resistivities, however, fall in the range 31–53 μΩ cm. Their only disadvantage lies in the finding that each 1 per cent. addition of molybdenum reduces *Bm* by 4 per cent. and lowers the Curie point by about 20°C.

The coercivity of the 3 per cent. molybdenum alloy is three or four times less than that of a 50–50 alloy, and its resistivity is appreciably larger. Its sole disadvantage is that the maximum induction attainable is some 20 per cent. less than that for the 50–50 alloy.

Solubility of Carbon in Molten Iron-Nickel Alloys

R. G. WARD and J. A. WRIGHT: 'The Solubility of Carbon in Molten Iron-Nickel Alloys.'

Jnl. Iron and Steel Inst., 1960, vol. 194, Mar., pp. 304–6.

The re-determination of the solubility of carbon in liquid iron-nickel alloys was undertaken in the hope that the dissolved carbon could be regarded as an 'indicator' of any lack of ideality of the iron-nickel solvent. Data obtained by other workers showed that the carbon solubility does not vary in a simple manner with the composition of the iron-nickel solvent, particularly at low temperatures. The solubility/composition relationship then determined was, however, insufficiently well-defined for detailed examination, and in the investigation now described the solubility of carbon in iron-nickel alloys was re-determined at a low temperature (1350°C.) at which deviations from ideality would be expected to be most pronounced.

Deviations from ideal behaviour were found and are interpreted to indicate a negative heat of mixing which is at a maximum at 75 at. per cent nickel. It is suggested that short-range ordering may be present in the melts.

Continuous Compaction of Nickel-Iron-Molybdenum Powders by Cyclic Pressing

See abstract on p. 162.

HEAT- AND CORROSION-RESISTING MATERIALS

Influence of Mode of Stressing in Fatigue Testing

B. CINA: 'The Effect of Mode of Stressing in Fatigue Testing.'

Jnl. Iron and Steel Inst., 1960, vol. 194, Mar., pp. 324–36.

Since most industrial fatigue failures probably occur as a result of stressing in cycles of alternating tension and compression, this mode of stressing has been the main subject of attention. A knowledge of the factors involved in pulsating tension or compression would, however, throw light on the fatigue process, and the investigation reported in the present paper was initiated to obtain data which would contribute to such knowledge.

The fatigue characteristics of three high-alloy steels

(a martensitic 13 per cent. chromium steel, a 20 per cent. chromium δ-ferritic steel, and the nickel-manganese-chromium austenitic steel 'NMC') were studied under the following modes of stressing: pulsating tension; alternating tension/compression: fluctuating compression/tension (using a mean compressive stress); and pulsating compression. Some of the 'NMC' and 20 per cent. chromium-steel specimens were tested after subjection to various degrees of cold working.

The results confirmed previous findings that a higher fatigue limit obtains in pulsating tension than in alternating tension/compression. With a mean compressive stress, both ferritic materials withstood a lower tensile stress in the alternating stress cycle than was the case for zero mean stress. No fatigue failures occurred in the 13 per cent. chromium and the austenitic steels during exposure to pulsating compression at stresses up to the 0·5 per cent. proof stress, even when, as in the case of the austenitic steel, the 0·5 per cent. proof stress was considerably increased by cold working. The 20 per cent. chromium steel proved subject to fatigue failure under pulsating-compression stress, but only when it had previously been adequately cold worked. Fatigue failures in pulsating tension, pulsating compression and alternating stress were accompanied by extrusion and intrusion effects.

The results, it was found, could be best represented in terms of a modified Goodman diagram based on the true fracture stress and the fatigue limit in alternating stress. Possible fatigue mechanisms are discussed.

Portable Creep-Testing Unit with Autographic Extensometer

C. WHEATLEY and R. GROSVENOR: 'Portable Creep-Testing Unit with Autographic Extensometer.'

Metallurgia, 1960, vol. 61, May, pp. 225-30.

Laboratories engaged in the testing of high-temperature alloys employ, among other equipment, stress-rupture and high-accuracy creep-testing machines of various types, each designed to meet a particular range of test conditions. At the Research Laboratory of The Mond Nickel Company, Ltd., 200 stress-rupture and 15 high-accuracy creep-testing machines of five different types have been in service for several years. The experience gained in their operation indicated the feasibility of designing a new machine of wider scope, sufficiently versatile to meet the majority of testing conditions currently needed or likely to be required in the foreseeable future. Details of the machine finally evolved are given in the present paper.

The machine was designed to satisfy the following requirements:

(1) With the exception of temperature-measuring equipment, it was to be self-contained and was to meet the requirements of *B.S.* 1686: 1950.

(2) It was to be capable of testing specimens over the load range 0·01-1 ton (1-1016 kg.)

(3) It was to be capable of providing specimen temperatures up to 1050°C. and controlling these to ±1°C.

(4) The extensometer was to be capable of autographically recording creep extension up to 0·1 in. (2·5 mm.).

(5) Apparatus for recording time-to-fracture of the specimens was to be incorporated into the machine.

Tensile and Short-Time Creep Properties of 'N-155' Sheet

E. C. BERNETT: 'Tensile and Short-Time Creep Properties of 'N-155' Alloy Sheet.'

Amer. Soc. Mechanical Engineers, 1959, *Paper* 59-*A*-27; 18 pp.

In missiles and similar structures in which the service life of the materials of construction is very short, much higher temperatures and stresses are permissible than those normally laid down for prolonged service. The need to determine the properties of the relevant heat-resisting materials under these new conditions has resulted in the development, by the Marquardt Corporation, of special test apparatus which permits rapid-rate tensile and compression testing, creep testing, low-frequency fatigue testing and thermal-cycling testing. Heating rates in excess of 200F.°/second (110C.°/second), and test temperatures higher than 3500°F. (1925°C.) are attainable. In the present paper details are given of an investigation in which the apparatus has been applied to evaluation of the tensile and short-time creep properties of 'N-155'* sheet.

At rapid rates of strain the high-temperature tensile strengths were up to 300 per cent. higher than those obtained at conventional testing speeds. At high temperatures and high stress levels, however, creep rates were found to be extremely rapid, and, in most cases, the creep strength became a critical factor. The rapid-strain-rate tensile data and high-stress creep data presented are discussed in relation to short-life designs.

'CD-4MCu' Precipitation-Hardenable Casting Stainless Steel

E. A. SCHOEFER: 'Stronger Cast Stainless Keeps Promises.'

Chemical Engineering, 1960, vol. 67, Mar. 7, pp. 164, 166, 168.

The high temperatures and pressures and severe corrosive conditions which are characteristic of many industrial processes have focused attention on the need for a material of construction which would satisfy the conjoint requirements of high strength and good corrosion-resistance. (The 18-8 chromium-nickel austenitic stainless steels, which have excellent corrosion-resistance, can be hardened only by cold working, an expensive operation restricted to strip, sheet or wire.) This article gives details of tests, carried out under laboratory and service conditions, on a precipitation-hardenable casting grade of stainless steel which,

* Nominal composition: iron 40, chromium 20, nickel 20, cobalt 20, per cent.

developed by the Alloy Casting Institute, was introduced three years ago with the claim that it offers excellent corrosion-resistance in combination with a strength twice that of an 18-8-type stainless steel.

The steel, designated 'CD-4MCu', is of the following composition: carbon 0·04 max., silicon 1 max., manganese 1 max., phosphorus 0·04 max., sulphur 0·04 max., chromium 25-27, nickel 4·75-6, molybdenum 1·75-2·25, copper 2·75-3·25, per cent. Data illustrating its excellent corrosion-resistance are included in the paper.

Castings are solution-treated in the range 1950°-2050°F. (1065°-1120°C.) and water quenched (to give a hardness of 250-270 B.H.N.); for maximum hardness (290-320 B.H.N.) they are aged for three hours in the range 850°-950°F. (455°-510°C.). In the as-cast condition the steel is of duplex austenite/ferrite structure; ageing results in the formation of scattered particles of sigma phase in the ferrite matrix. Typical mechanical properties in the solution-treated and hardened conditions are tabulated.

The steel is stated also to offer such advantages as good ductility when hardened, improved resistance to galling, good machinability, good weldability with satisfactory resistance to intergranular corrosion, and excellent castability. These factors are discussed.

A large part of the article is concerned with a review of plant tests indicating the suitability of the steel in applications involving exposure to corrosive or abrasive conditions.

See also

E. A. SCHOEFER: 'How New Cast Stainless Alloy Solves Problem Tasks.'

Iron Age, 1960, vol. 185, Mar. 10, pp. 126-8.

'Metamic 247': Nickel/Mullite High-Temperature Bearing Material

'Hot Bearings Made from Cermet.'

Engineering, 1960, vol. 189, May 20, p. 679.

This note gives details of a 75 nickel-25 mullite cermet developed for high-temperature bearings by Morgan Crucible Company, Ltd.

The cermet, designated 'Metamic 247', oxidizes to give a shiny grey-black nickel-oxide surface film which, when run against a hard 'Stellited' surface, exhibits satisfactory bearing characteristics without requiring lubrication. This film is, however, self-repairing only at temperatures above 500°C.: at lower temperatures it is worn off and abrasive (at room temperature the coefficient of friction is 0·5). The Company recommends that the oxide films on 'Metamic 247' and the 'Stellite' surface should be deliberately formed before running in.

Applications for which the material is considered promising are slow-moving or intermittent high-temperature bearings. To date, bearings have operated satisfactorily under the following conditions (all of which should not, however, be present concurrently): pressure, up to 500 p.s.i.; temperature, 500°-900°C.; surface speed, up to 22 ft./minute; coefficient of friction, about 0·3.

A table indicating the properties of 'Metamic 247' is reproduced below.

Bulk density	5·4-5·6 gm. per c.c.
Apparent porosity	Less than 8 per cent.
Cold bend strength ..	$21{\cdot}6\times10^3$ lb./sq. in.
Bend strength at	
500°C.	$22{\cdot}8\times10^3$ lb./sq. in.
800°C.	$25{\cdot}4\times10^3$ lb./sq. in.
1100°C.	$6{\cdot}3\times10^3$ lb./sq. in.
Thermal expansion.. ..	10×10^{-6} per °C. R.T. to 1000°C.
Thermal conductivity ..	0·036 CGS units
Hardness	200-250 V.P.N. before oxidation; 250-300 V.P.N. after oxidation
Young's modulus	$22{\cdot}5\times10^6$ lb./sq. in.
Dimensional limitations ..	$2\frac{1}{4}$ in. dia.; 3 in. long 2 in. dia.; 6 in. long
Operating clearances ..	0·004-0·008 in. cold
Counterface material ..	'Stellite 12'

Embrittlement of a 12-4-type Chromium-Nickel Steel during Heat-Treatment

G. T. BROWN and R.T. ALLSOP: 'Embrittlement of a 12%Cr-4%Ni Steel.'

Jnl. Iron and Steel Inst., 1960, vol. 194, Apr., pp. 435-42.

During a general study of a steel of 12 per cent. chromium-4 per cent. nickel type, it was noted that exposure to temperatures in the range 250-550°C could result in increased hardness and a severe reduction in room-temperature impact strength. The investigation reported in the present paper had a triple aim: (1) to determine the characteristic features of the embrittlement observed in the commercially produced steel; (2) to study the precipitation-hardening effects attributable to a nickel-silicon compound (designated 'S' phase); (3) to establish the composition of the 'S' phase.

The compositions of the steels studied are shown in the table, p. 173. Steels A and B were commercially produced to the same specification. Steel C was prepared in the laboratory (using high-purity materials and vacuum melting) to study the effect of reducing the silicon content to a low value. Apart from its silicon content, steel D was of similar composition to steel C and was used as a 'control'. Embrittlement was studied in the commercial steels as a function of the effects of (1) varying the initial heating temperature (commencing with the as-received, hot-rolled condition), (2) varying the subsequent ageing temperature, and (3) increasing the ageing time.

The magnitude of the changes resulting from exposure in the temperature range studied was found to be influenced markedly by the heat-treatment history of the steel: in particular, heating in the region of 680°C. before application of a lower-temperature treatment considerably delayed the onset of embrittlement. On the basis of the impact-transition curves and hardness data determined during the investigation, it is concluded that embrittlement arises largely as a result of a

Composition of Steels Studied
(*See abstract on p.* 172)

Cast	C %	Si %	S %	P %	Mn %	Ni %	Cr %	Mo %	Nb %	Al %
A	0·055	2·50	0·009	0·015	3·00	4·21	12·01	0·04	0·63	0·035
B	0·050	2·72	0·008	0·014	3·20	4·36	12·61	0·015	0·61	0·05
C	0·014	0·40			2·60	4·07	10·80		0·65	
D	0·010	2·71			2·54	4·02	11·17		0·53	

precipitation process (although the possibility of the occurrence of some degree of temper embrittlement is not ruled out).

The precipitating phases were studied by electrolytic-extraction techniques. In addition to niobium carbide, a new phase (the 'S' phase, the composition of which approximates to M_3Si where M is largely nickel) was found to be present. The results obtained show that embrittlement after short periods in the range 250–600°C. is due to the precipitation of 'S' phase rather than NbC. After long ageing period the development of sigma phase maintains the embrittlement produced by short ageing times.

Controlling the Properties of 'Nimonic' Alloys during Manufacture

A. DUNLOP: 'High-Temperature Alloys.'

Metal Industry, 1960, vol. 96, May 6, pp. 378–82.

In this article the author reviews the factors which, during the manufacture of nickel-base turbine-blading alloys, influence the degree to which the properties achieved in laboratory or pilot-plant development are attainable under production conditions. The points raised are illustrated in relation to the heat-treatment and fabrication procedures applied to alloys of the 'Nimonic' series.

In an introductory section the author briefly outlines the development of the 'Nimonic' alloys from the early member 'Nimonic 80' (essentially an alloy of 80–20 nickel-chromium base rendered age-hardenable by titanium and aluminium additions) to the later members of the series (alloys of nickel-chromium-cobalt base hardened with titanium, aluminium and molybdenum). Reference is then made to the 'balance factor' (determined by the following formula) which provides a composition ensuring optimum creep strength commensurate with satisfactory hot workability:

$$1\times\%Mo+2\times\%Al+4\times\%Ti=16\text{–}20.$$

Data illustrating the control attainable over properties by use of the formula are included in the paper.

The properties of the heat-resisting nickel-chromium-base alloys are achieved by heat-treatment involving solution-treatment in the range 1050°–1200°C. and subsequent ageing at 700°–800°C. The solution-treatment ensuring a fine grain-size results in inferior strength properties; that giving higher strength is associated with undesirable grain growth and decrease in fatigue and impact properties. In the manufacture of parts from ingots it has been normal practice to carry out the solution heat-treatment on completion of hot working, and to subject the component to ageing treatment after machining to final form. In discussing control of grain-size the author gives details of a procedure which is stated to achieve maximum creep strength without deleterious grain coarsening. The salient features of this treatment are:

(a) Carry out a major part of hot-work shaping.
(b) Solution heat-treat for a period of 5–10 hr. at 1100°–1200°C.
(c) Carry out the final part of the hot-work shaping at a temperature above the minimum solution-heat-treatment temperature.
(d) Apply a refining heat-treatment of 5 min. to 1 hr. at 850°–1050°C.
(e) Age-harden for 10–20 hr. at 700°–800°C.

The considerable advantages offered by this sequence are illustrated in relation to its application to an alloy of nickel-chromium-cobalt-molybdenum-titanium-aluminium type.

The adverse effects of cold working on the properties of such alloys are discussed: in particular, attention is drawn to the effects of surface work hardening caused by machining. Data included in this connexion demonstrate that heat-treatment for ½ hour at 1050°C. removes the effects of work hardening and restores creep strength.

The review concludes with a brief outline of the precautions necessary to ensure a balanced composition during melting and casting and to avoid unsoundness in the as-cast ingot. The use of Durville-type casting to prevent turbulence on pouring the ingot is illustrated.

Experience in the Operation of 'Nimonic 80A' Blades in Turbines Burning Natural Gas

G. R. HECKMAN and A. W. HERBENAR: 'Operating Experience of 'Nimonic 80A' First-Stage Buckets in Natural-Gas-Burning Turbines.'

Amer. Soc. Mechanical Engineers, 1960, *Paper* 60-*GTP*-8; 17 pp.

The investigation reported originated in the decision of the Gas Turbine Department, General Electric Company (taken at the time of the Korean War when certain alloying elements were in extremely short

supply) to substitute 'Nimonic 80A'* for the cobalt-base alloy 'S-816' previously adopted as the standard material of construction for the first-stage blades of its 5000-h.p. industrial gas turbines. An assessment of the long-time properties of 'Nimonic 80A' in terms of the data available indicated that at temperatures of 1190–1240°F (640–670°C.) and stress levels in the range 18,000–15,000 p.s.i. (8–6·5 t.s.i.; 12·5–10·5 kg./mm.^{2}) the performance of the alloy would be equivalent to that of 'S-816'. Accordingly 'Nimonic 80A' first-stage turbine blades machined from bar stock were incorporated into industrial gas turbines operating on natural gas. Failures, however, occurred prematurely within 15,000–20,000 hours of operation, and the investigation now reported was carried out to determine whether these failures were the result of abnormally high operating temperatures, material deficiencies, unreliable parametric extrapolations or a combination of all these factors.

The remaining portion of each of the failed blades was subjected to metallographic examination, blades from the same turbines which had not failed were examined metallographically and subjected to rupture tests, the properties of bar stock representative of the material from which the failed blades were machined were determined after exposure to various heat-treatment cycles (in some cases involving intermediate cold working), and, since extensive plans had been made to replace bar stock by forged blades, in the final phase of the investigation a preliminary study was made of the rupture strength of forged 'Nimonic 80A' turbine blades.

Discussion of the metallographic phase of the investigation is supplemented by reference to photomicro- and photomacrographs, and the results of the mechanical tests are summarized.

On the basis of the data obtained, the failures are considered to be explicable in two ways. The first explanation implies that the material was normal in every respect, and that failure was due solely to excessive operating temperatures. Whilst this theory is considered to be an oversimplification of the problem, it is nevertheless deemed consistent with temperature conditions which might have existed (especially at start-up) and which may have hastened the structural changes noted in the alloy. According to the second explanation, which is supported by considerable evidence and is thought more plausible, the 'Nimonic 80A' buckets failed prematurely in rupture, due to structural instability which caused embrittlement of the grain boundaries. The embrittling phase nucleated, and grew during service, as a result of the alloy's exposure to a single-ageing treatment in which the final ageing temperature was not too remote from the service temperature. Other factors noted as contributing to structural instability and growth of cellular colonies are: (1) the chemical inhomogeneity that existed in the segregated bar stock from which the blades were fabricated; (2) the strain energies induced by thermal cycling, normal operating stresses, and, particularly, cold-straightening or gagging; and (3) exposure to service temperatures near, or in excess of, the ageing temperature.

In a stage of the investigation concerned with corrective measures the effects of the following double-ageing treatment (which, it was considered, might confer greater ductility on the alloy) were evaluated:

1975°F. (1080°C.) — 8 hours — fast cool to
1560°F. (850°C.) — 24 hours — air cool;
1300°F. (705°C.) — 16 hours — air cool.

This treatment, in conjunction with modifications (in the contour of the leading edge of the blade and in the starting cycle) designed to minimize thermal stresses, has been applied to all 'Nimonic 80A' forged blades, and experience to date indicates that the blades will now give excellent long-term service.

* Composition: nickel 75, chromium 20·5, titanium 2·35, aluminium 1·25, carbon 0·1, per cent.

Relaxation Characteristics of 'Inconel' at Elevated Temperatures

C. R. KENNEDY and D. A. DOUGLAS: 'Relaxation Characteristics of 'Inconel' at Elevated Temperatures.'
Amer. Soc. Testing Materials, 1960, *Preprint* 68; 14 pp.

Many of the structural problems that arise in the design of components for high-temperature service stem from the occurrence of time-dependent plastic deformation. The resistance of a material to deformation can be measured by a variety of tests (e.g., the constant-stress creep test and the stress-relaxation test). In this paper the authors give details of a new stress-relaxation machine which, capable of testing materials at elevated temperatures, has the advantages of low cost, dynamic response and a control system capable of detecting a strain of 5×10^{-6}. The application of the machine and the significance of the results obtained are exemplified by data on the stress-relaxation characteristics of fine-grained and coarse-grained specimens of 'Inconel' at 1300°, 1500° and 1650°F. (705°, 815° and 900°C.).

The authors show that, using a single specimen and relatively short testing times, a complete set of stress/strain-rate values can be obtained at any desired temperature. The reliability of the testing device and the analytical model is illustrated in a comparison of values predicted from relaxation tests with those obtained in constant-stress creep tests. It is emphasized that the relaxation test is not a substitute for the creep test: it does, however, it is considered, provide a check on the accuracy of the law assumed for the constant-stress creep data, and provides additional information which will assist in establishing more exact analytical models to describe the deformation process.

Suitability of Nickel-Containing Materials for Use in Pressurized-Water Reactors

E. HOWELLS, T. A. McNARY, D. E. WHITE: 'Boiler Model Tests on Materials for Steam Generators in Pressurized-Water Reactor Plants.'
Corrosion, 1960, vol. 16, May, pp. 241t–5t.

In a pressurized-water nuclear-power plant the steam generator serves as the link between the primary and secondary systems. The tubing in the steam generator is unique, since it is exposed to both primary

and secondary water, and a material of construction for this application must therefore be selected on the basis of its resistance to both environments. The investigation now described was conducted to evaluate the behaviour of various materials on the secondary side of boiler models built and operated in simulation of a full-scale unit in a pressurized-water nuclear-power plant.

The screening of materials to determine their basic resistance to chloride stress-corrosion cracking was carried out in a separate, but associated, programme by means of tilting-autoclave tests on U-bend specimens. The screening tests indicated that carbon steel (with or without chromium additions), 'Croloy 16-1', 'Inconel', 'Monel' and commercial nickel were not subject to chloride stress corrosion (at least as compared with Type 347 18-8 Nb stainless steel), and these materials were selected for the boiler-model tests.

The test specimens were heat-exchanger models, approximately 18 in. (45 cm.) high and 6 in. (15 cm.) in diameter. Each of the 15 units consisted of the following components: a primary head, a horizontal tube sheet containing six active U-bend tubes with tube support plates, and a secondary shell. Three units each of 'Inconel', 'Monel', nickel and 'Croloy 2¼' were evaluated; 'Croloy 16-1' was exposed in only one unit; Type 347 stainless-steel specimens were exposed in the remaining two units (one of which incorporated a carbon-steel tube sheet).

With the exception of those in Type 347 steel, which were annealed at 1850°F (1010°C). for 35 seconds, all the wall tubes were installed in the units without heat-treatment. The 'Croloy 2¼' units and the 'Croloy 16-1' units were stress-relieved in an inert-gas atmosphere.

The nominal secondary-water conditions during steady-state operation were as follows:

pH	.. ..	$10{\cdot}9 \pm 0{\cdot}3$ (adjusted with NaOH)
Cl^-	.. ..	500 ± 50 p.p.m. (added as synthetic sea water)
$PO_4^{\equiv}$	.. ..	250 ± 50 p.p.m. (Na_2HPO_4)
Dissolved O_2	..	0·2-0·5 p.p.m. (by aeration)
Temperature	..	480-490 F. (250°-255°C.)
Pressure	..	600 p.s.i.g.

Full details are given of the intermittent operating conditions to which the specimens were subjected.

At the end of the 500-hour test period, the models were subjected to metallographic examination to determine the type and extent of general and pitting corrosion and susceptibility to stress-corrosion cracking.

Cracking occurred in the crevice surfaces of all the tube-to-tube sheet junctions of the stainless-steel tube unit; in the stainless-steel/carbon-steel unit, cracking occurred in only two of the tube-to-tube sheet junctions. This finding is discussed by the authors, together with such relevant points as pitting corrosion and the location of tubing areas most susceptible to stress corrosion.

It is deemed significant that no cracking occurred in 'Inconel', 'Monel', nickel, 'Croloy 16-1' or 'Croloy 2¼' in the same 500 hours of cyclic operation; and the results are considered to indicate the suitability (at least from the point of view of resistance to chloride stress corrosion) of the materials for use in steam generators.

Since cracking was detected only in Type 347 stainless steel, resistance to general corrosion and pitting corrosion became the main criterion by which the materials were compared. Nickel, and the high-nickel alloys 'Monel' and 'Inconel', proved the most corrosion-resistant (in certain cases displaying some surface dulling and very small pits at the crevice openings). Next in order of corrosion-resistance was 'Croloy 16-1', which exhibited pits up to 5 mm. deep on the bent portions of the tubes. (It is thought possible that the plastic deformation in the bend area rendered the material more susceptible to pitting, despite the stress-relief treatment to which it was subjected.) The general corrosion to which 'Croloy 16-1' was subject confirmed the original impression that its corrosion-resistance is not as high as that of the stainless steels or the high-nickel alloys: nevertheless, it is considered to offer promise as a steam-generator tubing material. Low-chromium steels such as 'Croloy 2¼' are regarded as too sensitive to pitting attack for this type of application.

Forging and Arc Welding of 'Inconel' for Nuclear-Power Applications

Materials of construction used in pressurized-water nuclear-power plant must satisfy stringent requirements: in particular, good corrosion-resistance, suitable physical and mechanical properties, and satisfactory fabrication characteristics are prerequisite. The heat-resisting alloy 'Inconel'* is known to possess the required corrosion-resistance (see, for example, abstract in *Nickel Bulletin*, 1960, vol. 33, No. 6, p. 152), but the information available was too sparse to resolve doubt as to its capacity to meet mechanical-property requirements in the fabricated (i.e., forged or arc-welded) condition. The investigations reported in the papers abstracted below were carried out to obtain the data necessary for this purpose.

C. L. DOTSON and R. L. ROSHONG: 'Nickel-Chromium-Iron Alloy ('Inconel') Forgings for Nuclear-Reactor Systems . . . A Summary of Forging Techniques and Mechanical Properties.'

Amer. Soc. Mechanical Engineers, 1960, *Paper* 60-MET-5; 7 pp.

The Cameron Iron Works, Inc., Houston (the Company with which the authors are associated) have produced many large integrally-forged stainless-steel gate-valve bodies, and associated valve bonnets, for use in the heat-transfer loops of pressurized-water reactors. When the demand arose for similar forgings with higher corrosion-resistance than, but similar strength to, those in A.I.S.I. Type 304 chromium-nickel stainless steel, the Company initiated a development programme to determine the feasibility of

* Composition: nickel 72 min., chromium 14-17, iron 6-10, manganese 1 max., copper 0·5 max., silicon 0·5 max., carbon 0·15 max., sulphur 0·015 max., per cent.

attaining, in heavy forged sections of 'Inconel', the strength properties required: 0·2 per cent. off-set yield strength, 30,000 p.s.i. (13·5 t.s.i.; 21·5 kg./mm.²); ultimate tensile strength, 80,000 p.s.i. (35·5 t.s.i.; 56 kg./mm.²); reduction-in-area, 35 per cent.

In the exploratory phase of the programme the effects of such forging variables as load, temperature, die lubricant and flow characteristics were studied in work involving the production of small experimental parts. Tensile properties were determined, at room temperature and 600°F. (315°C.), as a function of the various forging temperatures and post-forging heat-treatments evaluated.

The forging procedures developed as a result of these preliminary studies, and the mechanical properties associated with their use, are outlined in the paper in relation to data and experience obtained during the integral forging of 3150-lb. (1417·5-kg.) 'Inconel' gate-valve bodies.

It is concluded that 'Inconel' can, using conventional equipment, be forged into a variety of intricate shapes and sizes. Account must, however, be taken of the fact that 'Inconel', with its higher strength at elevated temperatures, is more difficult to forge than alloy steels. The fuels used for heating must be of low sulphur content, and forging temperatures must be accurately controlled if optimum results are to be obtained.

The mechanical properties of 'Inconel' forgings can be controlled to a significant degree by designing the die so as to ensure that the metal is sufficiently hot worked, by selecting appropriate thermal conditions during and after forging, and by varying the carbon content of the alloy. Ultimate-strength levels as high as 90,000 p.s.i. (40 t.s.i.: 63 kg./mm.²), and yield strengths as high as 45,000 p.s.i. (20·0 t.s.i.; 31·5 kg./mm.²) can, it is stated, be consistently and uniformly produced in heavy forged sections.

J. BLAND and W. A. OWCZARSKI: 'Arc Welding of a Ni-Cr-Fe ('Inconel') Alloy for Nuclear-Power Plants.'

Amer. Soc. Mechanical Engineers, 1960, *Paper* 60-*MET*-6; 15 pp.

'Inconel' is a weldable material, but the weldments produced to the date of the investigation reported by the authors had neither been intended to achieve, nor inspected in terms of, the quality levels required for nuclear service. Moreover, the alloy had not been welded in the section thicknesses required in such applications. When, therefore, 'Inconel' was selected, on account of its resistance to stress-corrosion cracking, as a material of construction for components of nuclear-power plant, work was carried out (1) to determine if the necessary butt welds and overlays could be successfully produced to the standard required, and (2) to evaluate the advantages and disadvantages of the various 'Inconel'-type filler metals and the arc-welding (shielded-metal-arc, inert-gas tungsten-arc, and inert-gas metal-arc) processes commercially available. Some study was also made of the effects of post-weld heat-treatments.

The work on structural welding involved determination of the soundness, hardness and mechanical properties of butt joints produced in $1\frac{1}{8}$- and $2\frac{5}{8}$-in. (2·8- and 6·5-cm.) sections, using 'Inconel' filler metals of various types. Welds joining 'Inconel' to itself and to Type 304 stainless steel were tested in the as-welded condition. 'Inconel'/carbon-steel welds were stress-relieved at 1150°F. (620°C.) prior to testing, so as to simulate the fabrication heat-treatment required for carbon-steel vessels.

In the weld-cladding programme, a three-layer overlay of 'Inconel' was deposited, using covered electrodes or inert-gas-welding techniques, on carbon-steel basis-metal plates. The suitability of the weld-cladding process and the filler metals employed was assessed in terms of fabrication advantages and the composition, soundness and mechanical properties of the deposits. The 'Inconel'-clad specimens were subjected to metallographic examination and to bend, hardness, and non-destructive (X-ray and liquid-penetrant) tests.

The paper contains full details of the welding conditions and filler metals studied, and the test data presented are supplemented by photomicrographs and photomacrographs indicating structures typical of the welds produced. The results show that weldments meeting the high standards required for nuclear-power-plant service can be produced with all the filler metals and processes evaluated. In general, 'Inconel'/'Inconel', 'Inconel'/stainless-steel, or 'Inconel'/carbon-steel weldments failed in the basis metal during tensile testing. The mechanical properties of weld metal deposited using 'Inconel'-type filler metals exceeded those of the annealed wrought basis metal.

Properties and Applications of Nickel-Molybdenum-base Corrosion-Resisting Alloys

W. KATZ: 'Nickel-Molybdenum Alloys as Corrosion-Resisting Materials.'

Reprint from *Maschinenmarkt*, 1960, vol. 66, Apr. 29; 4 pp.

The grades of wrought and cast nickel-molybdenum, nickel-molybdenum-chromium and nickel-chromium-iron-molybdenum alloys now commercially available under various trade names are finding wide acceptance in the chemical industry as materials of construction for plant exposed to temperatures and corrosive conditions of a severity which the chromium-nickel austenitic steels can no longer withstand (e.g., sulphuric acid at medium concentrations and hydrochloric acid at all concentrations and temperatures). Selection of the appropriate grade of alloy will ensure resistance to oxidizing or reducing conditions. In this paper the author reviews the properties and applications of the types of alloy falling within the composition ranges indicated in the table, p. 177.

After outlining the beneficial influence of molybdenum on the corrosion-resistance of nickel, the author evaluates the corrosion-resistance of each of the four types of alloy, considering the environments to which they are resistant and noting the

Ni	61 app.	54 app.	48 app.	40 app.
Cr	—	14·5-16·5	21-23	21
Mo	26-30	15·0-17·0	5·5-7·5	3
W	—	(3·0-4·5)	—	—
Fe	4-7	4·0-7·0	13·5-17·0	31
C	0·05 max.	0·08 max.	0·05 max.	0·05 Ti

industrial applications for which they have been found suitable. This textual information is supported by graphical data illustrating, for example, resistance to hydrochloric acid and sulphuric acid as a function of temperature and acid concentration. Data on mechanical properties are tabulated and the factors involved in the working, welding and heat-treatment of the alloys are briefly discussed. Sections covering metallurgical properties, structure and resistance to intergranular corrosion conclude the review.

Production and Properties of Sintered Stainless-Steel Parts

R. L. SANDS and J. F. WATKINSON: 'Sintered Stainless Steel. I. The Influence of Alloy Composition upon Compacting and Sintering Behaviour. II. The Properties of Stainless-Steel Powders Sintered in Dissociated Ammonia.'

Powder Metallurgy, 1960, No. 5, pp. 85-104; 105-15.

Part I. Improvements in the application of the atomization process to the production of chromium-nickel stainless-steel powders (described by WATKINSON in *Powder Metallurgy*, 1958, No. 1-2, pp. 13-23: abstract in *Nickel Bulletin*, 1959, vol. 32, No. 3, p. 65) have made available a wide range of pre-alloyed powders which do not depend upon a high silicon content for the attainment of a bright surface (and which do not therefore possess the undesirable characteristics associated with high-silicon stainless-steel powders). The investigation described was undertaken to determine the suitability of powders of this type for use in the production of dense stainless-steel components.

The following six types of powder, produced by inert-atmosphere atomization, were selected for study:

C %	Mn %	Si %	Ni %	Cr %	Mo %	Nb %
0·02	Nil	0·66	7·5	18·1	1·8	Nil
0·03	Nil	2·48	9·75	18·5	Nil	Nil
0·02	Nil	2·26	10·0	18·9	1·9	Nil
0·03	0·46	2·22	9·5	19·0	1·95	0·64
0·03	0·1	0·62	12·0	18·4	Trace	0·72
0·02	0·09	0·45	10·6	19·3	0·01	0·03

Specimens compacted at 50 tons/sq. in. (79 kg./mm.²) were sintered *in vacuo* for 1 hour at various temperatures, and the relationships between sintering temperature, density, strength and ductility determined. Two temperatures were then selected for further study: (1) that at which maximum density occurred without any melting; (2) that which caused 2-3 per cent. linear shrinkage. At each of these two temperatures specimens compacted at 30, 40 and 50 tons/sq. in. were sintered for 1 hour. The influence of sintering time was established for 0, 1, 8 and 20 hours' exposure *in vacuo*.

In other experiments, specimens compacted at 30, 40 and 50 tons/sq. in. (47, 63 and 79 kg./mm.²) were sintered in hydrogen for 1 hour at various temperatures, and in cracked ammonia at 1300°C.

The effect of compacting pressure was studied at pressures between 15 and 60 tons / sq. in. The specimens were then sintered *in vacuo* for 1 hour at 1300°C.

Test procedures are fully described and the data obtained are presented *in extenso*. Compacting and sintering properties were found to be to a large extent dependent upon composition. Molybdenum, silicon and niobium adversely affected the green density (although there are indications that this effect can be offset to some extent by raising the nickel content). The shrinkage for a given sintering temperature increased with increase in the silicon content or when molybdenum and/or niobium were present.

The following three types of alloy will, it is concluded from the data obtained, suffice to meet most industrial requirements:

C %	Si %	Ni %	Cr %	Mo %	Nb %
<0·05	0·5	10·0	18·0	—	—
<0·05	0·5	12·0	18·0	2·0	—
<0·05	0·5	12·0	18·0	—	0·5

Part II. In the investigation described in Part I the powders studied were, after compacting, sintered in sintering atmospheres and at sintering temperatures which are not likely to be available under industrial conditions. Stainless-steel powders intended for commercial production must therefore satisfy the following requirements: (1) they must exhibit high green density and adequate green strength after compacting under pressing loads in the range 30-50 tons/sq. in. (47-79 kg./mm.²); (2) sintering at 1150°C. in dissociated ammonia must result in high mechanical strength with less than 1 per cent. shrinkage.

The work described in Part II was initiated to determine the properties of sintered stainless-steel parts produced, under these conditions, from powders approximating to the optimum compositions established in Part I (i.e., 'Cosint 304L', 'Cosint 316L' and 'Cosint 347L'). Powder of a 13 per cent. chromium hardenable stainless-steel ('Cosint 410L') was also included in the investigation. Particular attention was paid to compressibility and green strength and to

the effects of mixing a lubricant (lithium stearate) with the powders.

The data recorded by the authors demonstrate the suitability of the austenitic stainless-steel powders for processing under typical industrial conditions. Green strength is adequate, and tensile strengths in the region of 30 tons/sq. in. (47 kg./mm.^{2}) and an elongation of 5 per cent. are obtainable after sintering. Achievement of these properties is dependent upon maintaining the silicon content of the powders below 1 per cent. Careful control of the particle shape is essential if green strength is to be adequate, and to ensure good compressibility, the nickel and chromium contents must be controlled with due regard to the amounts of silicon and molybdenum present.

Compositional Effects in the Corrosion of 18–8Nb and 18–8Mo Austenitic Steels

C. P. DILLON: 'Compositional Effects in the Corrosion of Type 347 and Type 316 Stainless Steel in Chemical Environments.'

Nat. Assocn. Corrosion Engineers, 16th Ann. Conference, 1960, *Preprint*; 9 pp.+tables and figures.

The investigation reported was carried out in an attempt to gain information on (1) the influence of individual alloying elements on the corrosion-resistance of stainless steels, and (2) the degree to which the results of a standard qualification test can be interpreted as a reflection of resistance to general corrosion.

In evaluating the effects of individual elements on behaviour both in qualification tests and process environments, the author has subjected the corrosion data (derived from the literature and from experimental work) to a graphical technique of multiple correlation. Data on the first of the two steels studied (A.I.S.I. Type 347 niobium-stabilized chromium-nickel stainless steel) are discussed in relation to the possible necessity of imposing (on the basis of an assessment of the results of the Huey test) composition requirements more stringent than those laid down for the commercial grades. The author's statistical analysis indicates that some improvement in corrosion-resistance can be effected by tightening compositional limits. The greatest improvement results from limiting the maximum silicon content, but chromium, manganese and nickel are beneficial (in descending order of importance) in minimizing corrosion rates, and the niobium/carbon ratio also plays an important rôle in this respect. It is considered, however, that quality control is, in practice, probably established by the qualification test itself, since variables other than composition significantly affect corrosion-resistance in boiling 65 per cent. nitric acid.

As a means of appraising compositional effects in Type 316 chromium-nickel-molybdenum stainless steel, and in view of the tendency to use qualification tests (particularly the Huey test) as criteria of the general corrosion-resistance of this steel, a statistical analysis was made of relevant data available from qualification and field corrosion tests. The author's findings indicate that the influence of the various compositional elements varies with the corrosive environment, and that a compositional range optimum for one type of service is not necessarily so for another. The performance of annealed material (or of sensitized extra-low-carbon material) in qualification tests cannot be used to assess general corrosion-resistance in other environments. In practice, the effects of compositional variations within the nominal A.S.M.E. range do not significantly influence corrosion-resistance.

Corrosion of Stainless Steels by Hot Hydrogen Sulphide

F. J. BRUNS: 'Corrosion of Stainless Steels by Hot Hydrogen Sulfide.'

Nat. Assocn. Corrosion Engineers, 16th Ann. Conference, 1960, *Preprint*; 10pp.+tables and figures.

In the refinery hydrodesulphurization units of the Sinclair Refining Company, Illinois, A.I.S.I. Type 304 18–8 chromium-nickel stainless steel is extensively used for the hot effluent/feed exchanger tube bundles. During the design of the units alternative types of stainless steel (particularly the stabilized, the extra-low-carbon and the chromium-manganese-nickel grades) were suggested for use: the investigation reported in this paper was initiated to evaluate the corrosion-resistance of such grades.

Four test spools containing specimens of the following eleven grades of stainless steel were exposed (for 3840 hours at 615°F. (325°C.) and 500 p.s.i.) in the effluent stream from a straight-run naptha-desulphurization unit: A.I.S.I. Type 304, 304L, 321, 347, 316 and 316L steels (i.e., 18–8, extra-low-carbon 18–8, 18–8Ti, 18–8Nb, 18–8Mo and extra-low-carbon 18–8Mo); Type 201 and 202 chromium-manganese-nickel steels; 'Tenelon' chromium-manganese steel; and Type 410 and 430 (15 per cent. and 13 per cent. chromium) steels. One set of specimens was exposed to the hot hydrogen sulphide in the as-received solution-annealed condition. The specimens comprising the other three sets were overlaid with a single weld bead of 25–20 chromium-nickel stainless steel: one of these sets was exposed in the as-welded condition; the second was exposed after heat-treatment in air for one hour at 1200°F. (650°C.); the third was subjected to stabilization treatment (heated for 16 hours in air at 1630°F. (885°C.)). After exposure, the test racks were removed and the degree of corrosion was determined by calculation of weight loss and by microscopical examination.

In a supplementary phase of the study, samples of Type 304 and 304L seam-welded stainless-steel exchanger tubing were subjected to various accelerated-corrosion tests (boiling 65 per cent. nitric acid; 6 per cent. copper sulphate; 43 per cent. magnesium chloride; and 6 per cent. H_2SO_3 solution through which hydrogen sulphide was bubbled at room temperature).

Full details are given of the results obtained from the investigation. The data presented indicate that the resistance of the chromium-manganese-nickel stainless steels to hydrogen sulphide at high temperatures is slightly better than that of the austenitic chromium-nickel stainless steels. The thermal stabilizing treat-treatment at 1630°F. increased the corrosion rate of all

the austenitic stainless steels tested. The corrosion tests on seam-welded Type 304L stainless-steel tubing in the as-welded condition revealed no sign of preferential weld-zone corrosion, and such tubing is considered an economical choice, except where chlorides are present, for refinery exchangers exposed to corrosive conditions.

High-Temperature Corrosion in Refinery Service

E. N. SKINNER, J. F. MASON and J. J. MORAN: 'High-Temperature Corrosion in Refinery Services.'

Nat. Assocn. Corrosion Engineers, 16*th Ann. Conference*, 1960, *Preprint*; 16 pp. + tables and figures.

In this review of the corrosion problems encountered in refinery and petrochemical plant operating at high temperatures, no attempt has been made to supply specific solutions to specific problems: rather the authors have tried 'to show the interrelation between chemical, physical and mechanical properties in a relatively broad general fashion, in the hope that, if detailed solutions could not be provided, a better insight into the capabilities of the several types of alloy, and of the factors involved in the selection of materials for high temperature service, would be obtained'.

The basic, because the least expensive, material of construction is mild steel, and the substitution of a more-highly-alloyed steel must be justified in terms of cost and performance. At temperatures higher than 950°F. (510°C.) the presence of chromium is required to prevent excessive scaling, the actual amount needed being roughly proportionate to the relevant service temperature. For somewhat severe service at higher temperatures, and particularly where high-temperature strength is necessary, use is made of the various chromium-nickel austenitic stainless steels and nickel-base alloys. In the present review (in which reference is made to a *bibliography* of 32 items) consideration is given to the factors influencing the choice between the aforementioned grades of material for use in refinery applications. The characteristics of the austenitic steels are considered in somewhat greater detail than, although not to the exclusion of, those of the others.

The various sections of the paper cover the problems involved in, and the materials used to withstand: oxidation in air; sulphidation (resulting from exposure to organic sulphides, hydrogen sulphide, sulphur dioxide); carburization and coke formation; corrosive deposits; aqueous corrosion; condensate corrosion; and naphthenic-acid corrosion. The physical and mechanical properties required for high-temperature service are also noted.

Case Histories of Stainless-Steel Failures in Petroleum Refineries

A. V. ALLESANDRIA and N. JAGGARD: 'Refiners Report New Cases of Stainless-Steel Failure.'

Petroleum Refiner, 1960, vol. 39, May, pp. 151–6.

In the majority of cases, failure of stainless-steel equipment in petroleum refiners can be attributed to stress-corrosion cracking or intergranular corrosion. In this article, which is based on a paper presented to the American Petroleum Institute, Division of Refining, Detroit, 1960, the authors review thirteen case histories of stress-corrosion and intergranular-corrosion failures reported (from previously unpublished sources) to have occurred in austenitic chromium-nickel stainless steels employed as materials of construction in refinery applications. The conditions under which failure occurred are first outlined, and then the action taken to prevent recurrence of cracking is discussed. The authors' main aim is to emphasize that the properties of austenitic stainless steels can be used to optimum advantage in petroleum refineries only if due consideration is given (1) to the suitability of a specific steel for use under the relevant service conditions, and (2) to the precautions (for example, stress-relief treatment) which might be necessary before use.

Five of the case histories are concerned with cracking in the presence of chloride ions (in a deoxygenating unit, pipe transporting spent catalyst and steam, U-bend tube bundles, and heat-exchanger tubes); three relate to stress-corrosion failures in caustic solutions (in a sleeve for a still nozzle, a baffle in the vapour outlet of an oil still, bubble caps in a caustic regenerator); five deal with intergranular-corrosion failures which occurred in tubes, furnace piping, vessels and vessel linings.

In a brief addendum to the article, failures attributed to sigma-phase embrittlement are discussed.

Corrosion Problems in a Synthetic Rubber Plant

N. MONSOUR: 'Discussion of Corrosion Problems in a Synthetic Rubber Plant.'

Nat. Assocn. Corrosion Engineers, 16*th Ann. Conference*, 1960, *Preprint*; 21 pp.

The Sarnia (Ontario) Plant of Polymer Corporation, Ltd., has the distinction of being the only fully-integrated synthetic-rubber plant in the world. Light hydrocarbon feeds (previously refinery waste gases) are processed through various stages to produce the heavier hydrocarbon feeds required to polymerize the finished butyl and butadiene-styrene copolymer rubbers. In the butyl unit the isobutylene is polymerized with traces of isoprene, at low temperature in the presence of a catalyst, to produce butyl rubbers. In the copolymer unit the butadiene and styrene monomers from the other units are reacted in a soap solution to produce a butadiene-styrene latex, which is coagulated, dried and packaged for shipment. This paper reviews corrosion and erosion problems selected as typical of those encountered during the plant's sixteen years' operation.

The corrosive media most commonly handled in the plant are: sulphuric acid; hydrochloric acid; sulphuric acid + brine mixture; brine solutions; soap solutions; glacial acetic acid; caustic (NaOH); low-pressure steam and hot condensate; superheated steam; river water; boiler feedwater treatment compounds; ammonia. The problems associated with each of these corrosives are discussed in relation to experience gained in the selection of suitable materials of construction.

The materials of construction employed in the plant, and on which information is given, are noted below.

Ferrous Materials:

Carbon-steel plate, pipe, bar, etc.
Cast iron, alloyed cast iron, high-silicon iron.
Wrought and cast grades of chromium-nickel and straight-chromium stainless steels (A.I.S.I. Types 304, 347, 316, 309, 310, 405, 410, 430, 446, 502).

Non-Ferrous Materials:

Copper and its alloys (e.g., 90-10 and 70-30 cupro nickels);
Aluminium alloys;
'Monel', 'K Monel', 'Inconel', 'Incoloy'.

Metal Linings:

Chemical lead, 'Monel' cladding.

Non-Metallic Materials.

Use of Cupro Nickel in Surface Condensers

H. A. TODHUNTER: 'Sea-Water Exposure of 70-30 Cupro-Nickel Surface Condensers.'
Corrosion, 1960, vol. 16, May, pp. 226t-8t.

The investigation described was initiated in an attempt to eliminate, in two 95,000 sq. ft. surface condensers which were to be incorporated into units of the Scattergood Steam Plant of the Los Angeles Department of Water and Power, the waterbox and tube-end problems associated with previous condensers in contact with sea-water, and, in particular to ensure that the condensers were not susceptible to galvanic corrosion.

Four means of achieving this aim were considered:
(1) By obviating the use of dissimilar metals in the cooling circuit.
(2) By incorporating galvanic protection as a means of neutralizing undesirable galvanic action.
(3) By incorporating protective coatings to minimize galvanic action.
(4) By a combination of two or more of the above designs.

These ideas were evaluated in condensers employing:
(1) Cast-iron waterboxes, 70-30 cupro-nickel tubes and tube sheets, and cathodic protection with magnesium anodes.
(2) Carbon-steel waterboxes with 70-30 cupro-nickel tubes and tube sheets. Protective coatings were applied to the steel, and electrical insulation was introduced between the 70-30 cupro nickel and the steel.
(3) 70-30 cupro-nickel waterboxes, tubes and tube sheets.

The suitability of these three types of condenser was assessed in terms of service performance and economic factors, an evaluation which led to the adoption of the third type. Tubing and tube sheet were to be in 70-30 cupro nickel containing about 0·5 per cent. of iron, but economic considerations required the fabrication of the waterboxes from steel clad with a 0·25 in. (0·6 cm.) lining of cupro nickel. It was found that iron dilution was less than 1·5 per cent. in the last weld pass, provided that four passes were used in joining the cladding. The butt-welding procedure used in the construction of the cupro-nickel-clad waterboxes is illustrated in the paper.

Corrosion of Nickel-containing Materials in Liquid Fluorine and Liquid Oxygen

F. W. FINK and E. L. WHITE: 'Corrosion of Materials by Fluorine and Liquid Oxygen.'
Nat. Assocn. Corrosion Engineers, 16th Ann. Conference, 1960, *Preprint*; 8 pp.

At atmospheric pressure fluorine is a liquid over a relatively small range of temperature (freezing point −363°F. (−220°C.); boiling point −306°F. (−188°C.)), and oxygen is a liquid at temperatures in the range −218° to −183°F. (−139° to −119°C.). The suitability of various metallic and non-metallic materials for storing or handling the two elements in the liquid phase forms the subject of the present paper.

The review is in general terms (though the paper includes data particularizing the corrosion-resistance, in liquid fluorine, of nickel, 'Monel', 'Inconel', 'Illium R', mild steel, chromium-nickel stainless steels, and aluminium, magnesium, and titanium alloys). Emphasis is placed on the factors which contribute to the resistance or susceptibility of the various types of materials discussed, and on the precautions necessary in using the materials for equipment handling the two elements.

The authors' overall conclusion is that most of the common structural materials (including stainless steels, nickel alloys, copper alloys, aluminium alloys and, in many applications, titanium alloys) are suitable for handling both liquid oxygen and liquid fluorine. Use of organic materials should be avoided wherever possible, and thorough cleaning of equipment prior to exposure is essential.

X-Ray Fluorescence Analysis of Electrolytically-Extracted Residues

H. HUGHES and L. GWILLIAM: 'Analysis of Extracted Residues by an X-Ray Fluorescent Method.'
Metallurgia, 1960, vol. 61, May, pp. 231-4.

The composition of a phase (e.g., $M_{23}C$) precipitated in alloy steels may vary considerably. Analysis of electrolytically-extracted residues could, therefore, provide information which, in conjunction with that obtained by means of the electron microscope and X-ray techniques, would contribute to a better understanding of the precipitation process. For reasonably accurate chemical analysis, the residue must be sufficiently large (0·5-1g.), but the achievement of this amount of residue involves a long and tedious process, and the actual analysis can be time-consuming. The authors have examined the feasibility of applying X-ray fluorescence spectroscopy to the analysis of such residues, and the method finally developed is described in the present paper.

The residue is fused at 1100°C, and the mixture is then dissolved in 25 ml. of nitric acid (specific gravity 1·2), the solution being warmed. The best fusion

mixture was found to be: 0·1g. of sample, 0·3g. of fused borax, 0·8g. of sodium carbonate. (It is possible to start with less than 0·1 g. of sample, and amounts as small as 0·05 g. can be analyzed by using a proportionately smaller volume of acid as solvent: the results, however, would be somewhat less accurate.) X-ray fluorescence examination of synthetic standard solutions prepared under the same conditions as the residue permits the number of counts per second to be plotted against the percentage weight of the element, and these calibration curves are then used in the subsequent analysis of the residue.

Details are given of the procedures used in the preparation of standard solutions for iron, cobalt, nickel, chromium, vanadium, molybdenum and titanium. The results of X-ray fluorescence analysis of specimen residues show good agreement with those obtained on the same specimen by means of conventional chemical techniques.

The method, which is stated to be quick, can be performed by an unqualified assistant, and is suitable for analysis of any material in powder form. Its application has at the moment been confined to analysis of the elements mentioned above, but copper, zinc and manganese could readily be included in the list, and others (such as niobium) with somewhat more difficulty. Once the calibration curves have been obtained, about six powders a day can be completely analyzed.

The application of the technique to analysis of phases present in 12 per cent. chromium steels and of *Chi* phase in the iron-chromium-nickel-titanium system is described.

X-Ray Fluorescence Analysis of Copper-Nickel-Iron Alloys

F. R. BAREHAM and J. G. M. FOX: 'X-Ray Fluorescence Analysis and its Application to Copper Alloys.'
Jnl. Inst. Metals, 1960, vol. 88, Apr., pp. 344–51.

The work reported was conducted to examine the feasibility of applying X-ray fluorescence analysis to determination of alloying elements in copper alloys.

Analysis of copper alloys by this technique was found to be rapid and reproducible. Although serious inter-element interference effects occur, these are explicable in terms of X-ray absorption and emission data, and systematic general procedures were developed by which the effects can be avoided in the determination of major alloying elements. The procedures, which have been applied to the determination of elements present in copper alloys at concentrations in the range 0·5–96 per cent., are exemplified by data relating to the analysis of binary and ternary alloys, in particular, a series of copper-nickel-iron alloys. At copper contents in the range 60–98 per cent., a standard deviation of approximately 0·15 per cent. copper was obtained with 1-minute counts, and the same counting time resulted in satisfactory accuracy for other elements present in amounts of 0·1 per cent. or higher.

Filler Rods and Wires for Inert-Gas Arc Welding Nickel-containing Steels and Alloys

See abstract on p. 161.

Influence of High-Temperature Exposure on the Corrosion-Resistance of 18-8-type Weld Metals

T. J. MOORE: 'Time-Temperature Parameters Affecting Corrosion of 18Cr-8Ni Weld Metals.'
Welding Jnl., 1960, vol. 39, May, pp. 199s–204s.

In a previous investigation the author had subjected partially-ferritic A.I.S.I. Type 347 (18-8Nb) weld metal, deposited using a covered electrode, to the nitric-acid and copper-sulphate/sulphuric-acid corrosion tests. A comparison of these results with those of similar tests on weld metals of Type 308L (extra-low-carbon 18-8) steel and of modified Type 347 steel demonstrated that, in general, the highest corrosion-resistance was exhibited by the Type 308L (0·036 per cent. carbon) weld deposit. In view of these findings, a further investigation was initiated with the dual aim of (1) determining the influence, on the corrosion-resistance of Types 308 and 308L weld metals, of prior ageing for various times at various temperatures, and (2) to ascertain the effects, in this connexion, of varying the carbon content of the deposit.

The composition and ferrite content of the weld metals studied are given in the table below. The deposits were produced using covered electrodes.

All-weld-metal specimens, machined longitudinally from the centre of stainless-steel butt weldments, were aged at temperatures ranging from 800° to 1300°F (425° to 705°C) for times ranging from 0·1 to 10,000 hours. In an attempt to reduce susceptibility to sensitization, some of the weld-metal specimens were subjected to various stabilizing heat-treatments prior to ageing. Resistance to intergranular corrosion was assessed in terms of the boiling-nitric-acid corrosion test.

Stainless-Steel Weld Metals
(See abstract above)

C %	Mn %	Si %	S %	P %	Cr %	Ni %	N %	Calculated % ferrite
0·026	1·20	0·44	0·013	0·021	19·70	10·88	0·070	5
0·036	0·68	0·33	0·011	0·016	18·51	10·63	0·048	3
0·047	0·73	0·33	0·015	0·015	18·77	10·84	0·050	2
0·067	0·62	0·35	0·016	0·006	19·45	10·50	0·040	4

The time/temperature/corrosion-rate relationship was found to follow a definite pattern, which is represented in the paper in the form of a three-dimensional drawing and in time/temperature/sensitization diagrams. The data show that exposure for long times at low temperatures (800–1100°F.: 425–595°C.) sensitized the weld metals to a marked degree, much more severely than conventional sensitizing heat-treatment involving 1 or 2 hours' exposure at 1200°F. (650°C). In general, the corrosion rate decreased with decrease in carbon content, although even the weld metal containing 0·026 per cent. carbon exhibited severe sensitization after low-temperature ageing.

A pre-ageing stabilizing heat-treatment of 12 hours at 1200°F. (650°C.) proved effective in inhibiting attack on 0·036 per cent. carbon weld-metal specimens aged at 1000°F. (540°C.) for up to 1000 hours. No suitable stabilizing heat-treatment has been found to inhibit the extremely high rates of corrosive attack exhibited by Types 308 and 308L weld metals aged at temperatures in the range 800–900°F. (425–480°C.).

ANALYSIS

Spectrographic Analysis of Electronic Nickel

See abstract on p. 163.

X-Ray Fluorescence Analysis of Electrolytically-Extracted Residues

See abstract on p. 180.

X-Ray Fluorescence Analysis of Copper-Nickel-Iron Alloys

See abstract on p. 181.

PATENTS

Porous Nickel Electrode for an Electrolyzer

A positive electrode for an electrolyzer comprises a solid backing plate supporting, on one face, a porous nickel electrode, the inner layer of which (adjacent to the backing plate) has a pore size larger than that of the outer, and thus provides pore spaces for passage of gas between the backing plate and denser portion of the electrode. The nickel particles of the porous electrode are coated with conductive lithium-containing nickel oxide, and a porous layer of non-conductive material (preferably magnesium oxide or green nickel oxide) is attached to, and covers the outer area of, the porous electrode in contact with the electrolyte.

The result of this construction is that the gases are liberated at the backs of the electrodes (i.e., the sides away from the electrolyte), thus preventing foaming of the electrolyte and obviating the need for a separating diaphragm.

F. T. BACON, assignor to E.R.A. PATENTS, LTD. *U.S. Pat.* 2,928,783.

Anti-Wear Lubricant

The invention is based on the finding that addition of both nickel and zinc dithiophosphates to a mineral-oil-base lubricant inhibits oxidation and deterioration of the oil, and substantially prevents severe surface wear of engine parts. The composition claimed consists of a mineral lubricating oil containing minor amounts of oil-soluble zinc and nickel dithiophosphate diesters (the organic portions of which contain 4–14 carbon atoms), the zinc and nickel diesters being present in amounts to provide 0·03–0·02 per cent. of phosphorus each.

M. P. KLEINHOLZ, assignor to SINCLAIR REFINING COMPANY. *U.S. Pat.* 2,937,992.

Aluminium Plating of Nickel

A thick, adherent, impermeable coating of aluminium is applied to copper, iron, nickel, steel, zinc or brass by (1) pre-treatment in a fatty acid having a chain of at least 10 carbon atoms, (2) electrodeposition of aluminium from a water-free organic solution of an aluminium salt (preferably a diethyl-ether solution of aluminium chloride and lithium hydride).

Also claimed is a process by which uranium is electroplated with nickel from a nickel-sulphate-containing electrolyte, dried, immersed in oleic acid, electroplated with aluminium (from a water-free diethyl-ether solution containing aluminium chloride 332, lithium hydride 6, g./L.), and finally heated at 510°C. for 1 hour at a maximum absolute pressure of 10μ.

W. C. SCHICKNER, assignor to U.S. ATOMIC ENERGY COMMISSION. *U.S. Pat.* 2,934,478.

Bright-Nickel Plating Solution

Bright fine-grained nickel is electrodeposited from an aqueous acidic solution containing one or more of the salts nickel sulphate, nickel chloride, nickel fluoborate and nickel sulphamate. The nickel-ion concentration is in the range 7–130 g./L., and dissolved in the solution is an acetylenically unsaturated sulphonic acid having 3–14 aliphatic carbon atoms in the molecule. The solution preferably contains also 0·1 g./L. to saturation of a sulphur-containing brightener in the form of an organic sulphonamide, sulphonimide or sulphonic acid.

UDYLITE RESEARCH CORPORATION. *Brit. Pat.* 836,802. *Similar to U.S. Pats.* 2,800,440–2.

Electroless Nickel Plating of Magnesium

A principal object of the invention is to provide an aqueous chemical plating solution suitable for plating magnesium with nickel coatings stated to be continuous, hard, semi-bright, adhesive and

capable of being buffed to a mirror-like surface. The solution contains fluoride 0·15–2·5, nickel (obtained from soluble nickel salts other than nickel chloride or nickel sulphate) 0·04–1·4, hypophosphite 0·04–2·6, mole/L., and is buffered to a pH in the range 3·5–7. The preferred nickel salt is nickel carbonate. The application of the solution to plating aluminium, iron or copper is also claimed.

DOW CHEMICAL COMPANY. *Brit. Pat.* 830,597.

Direct Nickel Plating of Zinc

According to the claims of the patent, zinc or zinc-base alloys are plated with bright nickel directly (i.e., without the necessity of prior copper plating) from a solution comprising: nickel sulphate 75–300, boric acid 10–50, 2-mercaptobenzimidazole (as a brightener) 0·01–0·5, a carrier promoting ductility of the deposit (preferably a saccharin, a naphthalene mono-, di-, or tri-sulphonic acid and/or a sodium salt of these acids) 2–20, g./L., and a water-soluble salt (preferably a sodium salt) or derivative of ethylenediamine tetra-acetic acid equal or equivalent to 20–140 g./L. of the acid. The pH of the bath is adjusted to a value between 3 and 6. The solution preferably contains chloride ions (nickel chloride 25–100 g./L.).

M. L. ALKAN, LTD. (inventor A. MOHAN).
Brit. Pat. 837,050.

Chemical Nickel Plating of Titanium, Zirconium or Hafnium

An adherent coating of nickel is deposited on titanium, zirconium or hafnium by a procedure which involves: cleaning the metal surface; pickling in an aqueous solution containing 8 mole/L. of hydrochloric acid, 4·5 mole/L. of hydrofluoric acid, and a mild oxidizing agent; plating with nickel from a solution of the nickel-cation/hypophosphite-anion type; and finally subjecting the plated component to a diffusion heat-treatment at 425°C. min.

The application of the invention to titanium-base alloys is specifically claimed.

W. G. LEE and E. BROWAR, assignors to GENERAL AMERICAN TRANSPORTATION CORPORATION.
U.S. Pat. 2,928,757.

Deposition of Nickel-Boron Alloys by Chemical Plating

Nickel-boron or cobalt-boron-alloy coatings, comprising an interstitial solution of boron (4·5-wt. per cent.) in nickel or cobalt, and characterized by the fact that they show no boron lines in the X-ray diffraction pattern, are deposited from an aqueous alkaline chemical plating solution containing a nickel or cobalt salt, a borohydride, and (as a nickel or cobalt sequestering agent) ammonia or an organic complex-forming compound containing one or more amino, imino, carboxy or hydroxy groups. The deposition of such alloys on nickel, cobalt, iron, steel, aluminium, zinc, palladium, platinum, copper, brass, manganese, chromium, molybdenum, tungsten, titanium, tin, silver or carbon is claimed.

The alloys covered by the patent are stated to provide bright, hard, uniformly-thick, corrosion-resistant coatings relatively free from porosity.

E.I. DU PONT DE NEMOURS AND COMPANY.
Brit. Pat. 836,480.
Similar to French „ 1,197,797.

Chemically-Nickel-Plated Tank Cars

A container, such as a railway tank car, is provided with an adherent, wear-resistant, corrosion-resistant lining by deposition (from a plating solution of the nickel-cation/hypophosphite-anion type) of a coating consisting of nickel 88–94, phosphorus 6–12, wt. per cent. The properties of the lining are modified, as appropriate, by heat-treatment at a temperature in the range 100°–1100°C.

Four types of coating are attainable: (I) In the as-deposited condition, the coating comprises an amorphous solid, consisting of a metastable undercooled solution of phosphorus in nickel (hardness about 525 V.P.N.); (II) Heat-treatment in the range 100°–400°C. causes some precipitation of Ni_3P (hardness 575–1000 V.P.N.); (III) Heat-treatment in the range 400°C. to a temperature below the melting point (880°–1100°C.) converts (II) to a stable solid characterized by the presence of substantial quantities of micro-crystals of Ni_3P dispersed in the nickel matrix (hardness 575–1000 V.P.N.); (IV) Heat-treatment above the melting point converts (III) to a nickel-phosphorus alloy characterized by a dispersion of nickel dendrites or solid Ni_3P crystals in the eutectic composition. The advantages and production of these various types of lining are discussed in the preamble to the patent.

GENERAL AMERICAN TRANSPORTATION CORPORATION.
Brit. Pat. 834,561.
Similar to Belgian „ 547,411.
„ „ *French* „ 1,151,544.
„ „ *U.S.* „ 2,908,419.

Nickel-Plated Iron Particles

Iron particles, preferably 5–15 μ in diameter, are gas plated with nickel to a uniform thickness insufficient to change their normal physical characteristics. The coating, which prevents oxidation of the iron particles and the associated deleterious variations in their electrical and magnetic properties, is obtained by suspending the particles in a stream of gas (e.g., hydrogen), heating them inductively, and exposing them to a heat decomposable gas (nickel carbonyl).

H. J. HOMER and J. R. WHITACRE, assignors to COMMONWEALTH ENGINEERING COMPANY OF OHIO.
U.S. Pat. 2,933,415.

Improved Nickel-Iron Magnetic Alloy

Oriented face-centred-cubic crystalline sheet, claimed to exhibit exceptionally useful dynamic magnetic properties, is produced by rolling a casting (consisting of 55–70 per cent. nickel, 1–3 per cent. molybdenum,

remainder iron, and having a plurality of elongated columnar grains) in a direction substantially perpendicular to the longitudinal axes of the columnar grains. The alloy is hot-rolled at at least 1000°C., annealed for one hour in hydrogen at 900°–1000°C., rapidly cooled, reduced 55–70 per cent. by cold-rolling, annealed for 4½–5 hours in hydrogen at at least 650°C., rapidly cooled, reduced 95–99 per cent. by cold-rolling to the final thickness, recrystallized by annealing for 10–30 minutes in hydrogen at 500°–1000°C., annealed for 2–4 hours in hydrogen at 1050°–1250°C., and finally magnetically annealed at 650°C. in hydrogen for one hour in a magnetic field of 10–12 Oersteds. The treated alloy is characterized by high permeability, low coercive force and high remanence or residual inductance.

GENERAL ELECTRIC COMPANY. *Brit. Pat.* 831,129.
Similar to Belgian „ 548,601.
„ „ *U.S.* „ 2,891,883.

Nickel-containing Ferromagnetic Material for Piezo-Magnetic Vibrators

The ferromagnetic material of spinel structure covered by the patent contains NiO 29–47, CuO 3–20, CoO 0·5–2, Fe_2O_3 50–52, g. mol. per cent., and is produced by sintering a mixture of the oxides, or oxide-forming materials, at 1000°–1400°C. (preferably 1200°–1300°C.). The NiO and CuO may be replaced by ZnO in amounts up to 10 per cent.

In its use for piezo-magnetic vibrators the material covered exhibits properties superior to those of known ferrites.

N.V. PHILIPS' GLOEILAMPENFABRIEKEN.
French Pat. 1,216,028.

Production of Nickel-Iron-Alloy Spiral Balance Springs

Self-compensating spiral balance springs are produced from nickel-iron alloys by a process which, involving thermal dissociation of volatile metal compounds and diffusion annealing, ensures that only the surface of the spring ribbon is provided with age-hardening constituents (e.g., molybdenum, titanium, beryllium) and is thus hardened during solution-treatment, quenching and ageing. The spring is characterized by a relatively soft core and a hard surface and combines the advantages of high rigidity and a high modulus of elasticity with resistance to fracture.

VEB GLASHÜTTER UHRENBETRIEBE (inventor, A. BECK).
German Pat. 1,077,027.

Low-Alloy Die Steel

An air-hardening steel, suitable for use as a forming die, and characterized by high impact-resistance, wear-resistance, hot hardness, and resistance to thermal checking, falls within the following composition range: carbon 0·5–0·6, silicon 1·25–2·5, manganese 1·5–2·5, chromium 3–4, nickel 1–2, tungsten 0·75–1·5, vanadium 0·75–1·5, per cent. The steel is stated to give improved die life in both hot- and cold-forming operations, and to be particularly useful for forming high-temperature alloys.

The steel is formed at a temperature in the range 2050°–2100°F. (1120°–1150°C.), annealed at 1475°F. (800°C.) for about 1 hour, cooled to 1275°F. (690°C.) and held for about 4 hours, cooled to room temperature, reheated to 1275°F. and held for about 6 hours, and finally cooled to room temperature.

GENERAL ELECTRIC COMPANY. *Brit. Pat.* 830,775.
Similar to U.S. „ 2,857,267.
Similar to South African „ 3756/58.

Molybdenum-Nickel-Vanadium-Titanium Structural Steel

The low-alloy molybdenum-nickel-vanadium-titanium steel which is the subject of the patent is intended for structural and pressure-vessel applications requiring a high yield point in conjunction with good ductility and weldability. Compositional limits are as follows: carbon 0·08–0·30, silicon 0·15–0·35, manganese 0·90–1·40, nickel 1·25–1·75, vanadium 0·05–0·13, molybdenum 0·10–0·30, titanium 0·005–0·045, aluminium 0·03–0·10, per cent., remainder iron. Within these limits, preferred ranges of composition are claimed for sheets, bars, rods or shapes having a maximum cross section of 3 in. (7·5 cm.) and for plates, forgings, shapes and bars of cross section greater than 3 in.

LUKENS STEEL COMPANY. *Brit. Pat.* 838,960.
Similar to Canad. „ 577,578.
„ „ *U.S.* „ 2,853,379.

Cobalt-Nickel-Vanadium High-Temperature Alloy

The invention is based on the finding that alloys containing vanadium and cobalt and/or nickel are capable, within a narrowly defined concentration range, and after heat-treatment at temperatures higher than 500°C., of assuming a state of order in which they exhibit an increase in hardness and tensile strength at high temperatures: this range is delimited in the claims of the patent in relation to an accompanying ternary diagram.

Since these properties are not due to precipitation, but to a specific state of order, the hardness achieved by heat-treatment is determined exclusively by the temperature of the treatment and not by its duration. The particular advantage of the alloys lies in the fact that no softening occurs however long the load is sustained at elevated temperatures. The alloys may contain up to 1 per cent. cerium, up to 0·5 per cent. boron, up to 0·5 per cent. carbon, up to 0·5 per cent. nitrogen, and up to 10 per cent. of one or more of the following: aluminium, chromium, iron, manganese, molybdenum, tungsten, titanium, tantalum, niobium, zirconium, silicon.

Heat-treatment comprises slow cooling from a temperature above 1000°C., or rapid cooling from a temperature above 1000°C. and annealing at 400°–1000°C. (preferably 400°–750°C.).

DEUTSCHE EDELSTAHLWERKE A.G.

Brit. Pat. 835,372.
Similar to German „ 1,061,520.

Precipitation-Hardenable Austenitic Stainless Steel

A weldable austenitic stainless steel, which is readily workable in the pre-hardened condition and then hardenable (to give high strength at room temperature and elevated temperatures) by heat-treatment at comparatively low temperatures, consists of: carbon 0·2–1·5, chromium 12–30, nickel 2–7, manganese 4–16, vanadium 0·5–2, tungsten 0–4, molybdenum 0–4, copper 0–4, niobium 0–1·5, nitrogen 0–0·75, per cent. The basis of the invention is the discovery that carbon and vanadium, when present in critical percentage, co-act to render the austenitic composition hardenable by heat-treatment.

Articles are fabricated from the steel by the following procedure: heating for ½ hour in the range 2000°–2100°F. (1095°–1150°C.), water-quench, fabricating the ductile pre-hardened steel, and then hardening at 1300°F. (705°C.).

ARMCO INTERNATIONAL CORPORATION.

Brit. Pat. 833,536.

Nickel-containing Seal Materials for High-Temperature Applications

The materials covered by the two patents are stated to be suitable for use in rotating seal components (e.g., as used in aircraft) subjected, in the absence of a lubricant, to temperatures of up to about 1350°F. (735°C.) and sliding at speeds up to about 30,000 ft./minute (9,000 m./minute) at loads of up to 14 p.s.i.g. (1 kg./cm.^{2} above atmospheric pressure).

Patent 2,927,370 claims a composition containing tungsten boride 60–90, nickel 10–20, silver 5–20, wt. per cent.

Patent 2,928,167 claims a composition consisting of chromium nitride 50–70, nickel 20–30, wt. per cent., remainder (and between 10 and 20 wt. per cent.) silver.

The powder-metallurgical procedures used to prepare the bearing materials are outlined in the preamble to the patents. It is stated that compositions covered by the two patents were tested against mating surfaces of tool steel and 'Inconel'.

R. H. BASKEY and E. D. FISHER, assignors to HORIZONS, INC. *U.S. Pat.* 2,927,370.

R. H. BASKEY, assignor to HORIZONS, INC. *U.S. Pat.* 2,928,167.

Protection of Molybdenum from High-Temperature Oxidation

Molybdenum or a molybdenum-base alloy is protected from oxidation at high temperatures by means of a tenacious and continuous oxidation-resistant coating applied by (1) electrodeposition of a chromium coating, (2) deposition of a nickel strike at least 0·0005 in. (0·0125 mm.) thick from a high-chloride solution, (3) electrodeposition of a second low-stress nickel coating, (4) subjection of the plated component to a slow heat-treatment cycle (at least part of which must be at a minimum temperature of 1600°F. (870°C.)) in a reducing atmosphere, (5) electrodeposition of a second coating of chromium onto the nickel, and (6) subjection of the multiple-coated component to a second slow heat-treatment cycle (at least part of which must be at a minimum temperature of 1800°F. (980°C.)) in a reducing atmosphere.

The invention is intended mainly, but not exclusively, to provide a means of conferring, on molybdenum gas-turbine blades, resistance to high-temperature oxidation for longer periods than hitherto possible.

GENERAL ELECTRIC COMPANY (inventors, G. F. ALBERS and F. S. SCHULTZ). *Brit. Pat.* 831,786.

Nickel-containing β-Brasses with Increased Resistance to Stress Corrosion

According to the present invention, the resistance of high-tensile β-brasses to stress-corrosion cracking is greatly increased by the addition of between 1–2·5 (preferably 1·5 min.) per cent. of nickel and/or cobalt.

The composition range claimed is: copper 53 min., manganese 0–3·4, aluminium 3–6, iron 1–4, nickel and/or cobalt > 1–2·5, per cent., remainder zinc. The main application of the alloys is in articles (e.g., ships' propellers and accessories) exposed to attack by sea water.

A. R. BAILEY. *Brit. Pat.* 833,288.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Trade Marks*.

A Publication prepared by

DEVELOPMENT AND RESEARCH DEPARTMENT

of

THE MOND NICKEL COMPANY LTD.

PRINTED IN ENGLAND BY WIGHTMAN MOUNTAIN LTD.
WESTMINSTER, LONDON S.W.1